TARD-ATD-ARES-0006v.1

# An Aerial Radiological Survey of the California Bay Area

Survey Dates: August 27 – 31, 2012

RSL
REMOTE SENSING LABORATORY

U.S. DEPARTMENT OF HOMELAND SECURITY

AERIAL MEASURING SYSTEMS

## DISCLAIMER

TARD-ATD-ARES-0006v.1
December 2012

# An Aerial Radiological Survey of the California Bay Area

**Survey Dates: August 27 – 31, 2012**

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This work was performed for the Department of Homeland Security's Domestic Nuclear Detection Office by National Security Technologies, LLC, under IAA HSHQDC-11-X-00376.

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## EXECUTIVE SUMMARY

In late August 2012, at the request of the Department of Homeland Security's Domestic Nuclear Detection Office (DNDO), an aerial radiological survey of select portions of the California Bay Area was conducted by the Department of Energy's Remote Sensing Lab's Aerial Measuring Systems (AMS). Data collected during the survey were used in the DNDO Airborne Radiological Enhanced-sensor System (ARES) program to validate simulations of background radiation rates. As this was a research mission, specific areas selected for the survey were chosen for their suitability for that mission. Selection was not prejudiced by expectations of any particular results.

The data were also analyzed by AMS using standard techniques to produce maps showing gross count rates and exposure rates. Aside from a few signals consistent with radioisotopes used in nuclear medicine, nothing other than the expected normal background was found. Finding signals from medical isotopes is common in populated areas. However, because these data are part of an effort to improve aerial radiological detection methods, future analyses may reveal signals not found by standard AMS techniques.

At the request of the Department of Energy, Treasure Island, Yerba Buena Island, and Hunter's point were surveyed for the City of San Francisco and the California Department of Public Health. AMS analysis of data collected in these areas showed only normal background radiation, consistent with naturally-occurring radioisotopes. These data were not used by the ARES program.

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## ACRONYMS

| | |
|---|---|
| ADS | Advanced Digital Spectrometer |
| AGL | Above Ground Level |
| AMS | Aerial Measuring System |
| ARES | Airborne Radiological Enhanced-sensor System |
| cps | Counts Per Second |
| DHS | Department of Homeland Security |
| DNDO | Domestic Nuclear Detection Office |
| DOE | Department of Energy |
| FBO | Forward Base of Operations |
| HPGe | High-Purity Germanium |
| NaI(Tl) | Thallium-activated Sodium Iodide |
| PMT | Photomultiplier Tube |
| RSI | Radiation Solutions Inc. |
| RSL | Remote Sensing Laboratory |
| USGS | United States Geological Survey |
| μR/hr | Micro-Roentgen per hour |

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# 1 INTRODUCTION

In late August 2012, at the request of the Department of Homeland Security's (DHS) Domestic Nuclear Detection Office (DNDO), an aerial radiological survey of select portions of the California Bay Area was conducted by the Department of Energy's (DOE) Remote Sensing Lab's (RSL) Aerial Measuring Systems (AMS). Data collected during the survey were used in the DNDO Airborne Radiological Enhanced-sensor System (ARES) program to validate simulations of background radiation rates. The data were also analyzed by AMS using standard techniques to produce maps showing gross count rates and terrestrial exposure rates. At the request of DOE several additional areas were surveyed for the City of San Francisco and the California Department of Public Health.

The ARES program is a DNDO-sponsored research and development effort that will result in improved methods to detect and localize radiological sources from an airborne platform. It incorporates improvements in radiation sensor technology and advanced processing algorithms for data collected with the new sensors.

Section 2 of this report discusses aerial survey methods, and section 3 covers background radiation. The surveyed areas are described in section 4. Section 5 outlines survey operations, and section 6 gives some details about AMS analysis techniques. Results are presented in sections 7 and 8, with the former focusing on the statistics of the entire survey, and the latter giving details of results from each area.

# 2 SURVEY METHODS

## 2.1 Aerial Measurements

AMS has been conducting aerial surveys since 1967, including planned surveys over metropolitan areas (AMS, 2011) and the Nevada National Security Site (Hendricks & Reidhauser, 1994), as well as emergency response missions such as the Fukushima Daiichi nuclear power plant accident (Lyons & Colton, 2012). General details of aerial radiological surveys have been previously published (Proctor, 1997).

The California Bay Area survey was planned to provide one-hundred percent coverage of the designated survey areas with the aerial detector footprint. This task was accomplished by flying sets of parallel flight lines across the survey areas using one of AMS's helicopters carrying a radiation detection system (see Figure 1). Normally, the distance between flight lines is twice the altitude above ground level (AGL) of the aircraft, but for this survey a denser data set was desired. Therefore, the flight altitude was 300 ft AGL and the flight lines were spaced 300 ft apart. The areas were surveyed at a nominal ground speed of 70 knots (~118 ft/sec.)

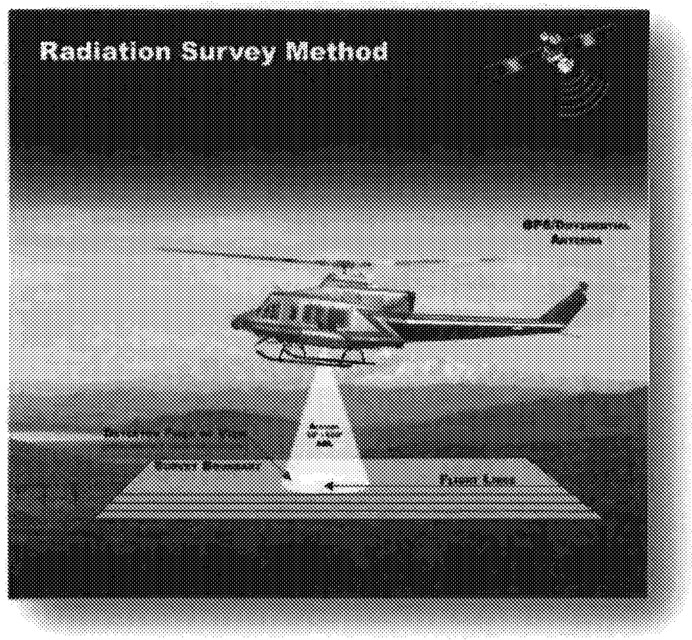


**Figure 1. Schematic diagram of the aerial survey method.**

**The helicopter, carrying the radiation detection equipment, flies a series of parallel lines over the survey area. The detector collects data from a circular area on the ground with a diameter that is roughly twice the height of the detectors above the ground.**

Completing the Bay Area survey area required 282 flight lines needing about 30 hours of flight time to complete. As the helicopter's fuel capacity restricted the time for an individual flight to approximately 2.5 hrs, a total of 14 flights were required to completely cover the survey area.

## 2.2 Survey Equipment

AMS utilized a Bell 412 helicopter (Figure 2) and a detection system acquired from Radiation Solutions Inc. (RSI) for AMS applications. The Bell 412 is a twin-engine utility helicopter that has been manufactured by Bell Helicopter since 1981. With a standard fuel capacity of 330 gallons, it is capable of flying for up to 3.7 hours, with a maximum range of 356 nautical miles and a cruising speed of 122 knots. However, with the AMS radiation survey configuration of 12 detectors, four crew members (two pilots, a mission scientist and an equipment operator), the AMS Bell 412 was capable of 2.5 hours of flight time with a survey speed of 70 knots (120 feet/sec) at the survey altitude of 300 ft AGL.

Figure 2. AMS Bell 412 helicopter used for aerial radiological surveys.

Detector pods are seen on the right and left sides of the helicopter.

The RSI system, configured for AMS applications, employs a total of twelve thallium-activated sodium iodide (NaI(Tl)) crystals, fabricated as log-type detectors with dimensions of 2" × 4" × 16" (128 cu in ≈ 2 liter). These detectors are packaged in four RSX-3 units. Each RSX-3 unit is a carbon fiber box containing three NaI (Tl) logs. Each NaI(Tl) log is coupled to a photomultiplier tube (PMT) that produces analog signals for analysis by an Advanced Digital Spectrometer (ADS) module attached to each PMT.

Data from each of the three ADS modules is sent to one of four RS-701 consoles. An Edak case houses an RS-501 aggregator box and a power distribution unit. The RS-501 receives and consolidates the data from the RSX-3s for data display and storage. Four RSX-3 boxes and four RS-701 consoles are fitted into the externally mounted aluminum pods (two RSX-3s and two RS-701s per pod) on the left and right sides of the Bell 412 helicopter (see Figure 3). The Edak case and a laptop computer with the data collection and display software are mounted inside the helicopter. An operator uses the laptop to monitor data collection and system performance during flight.

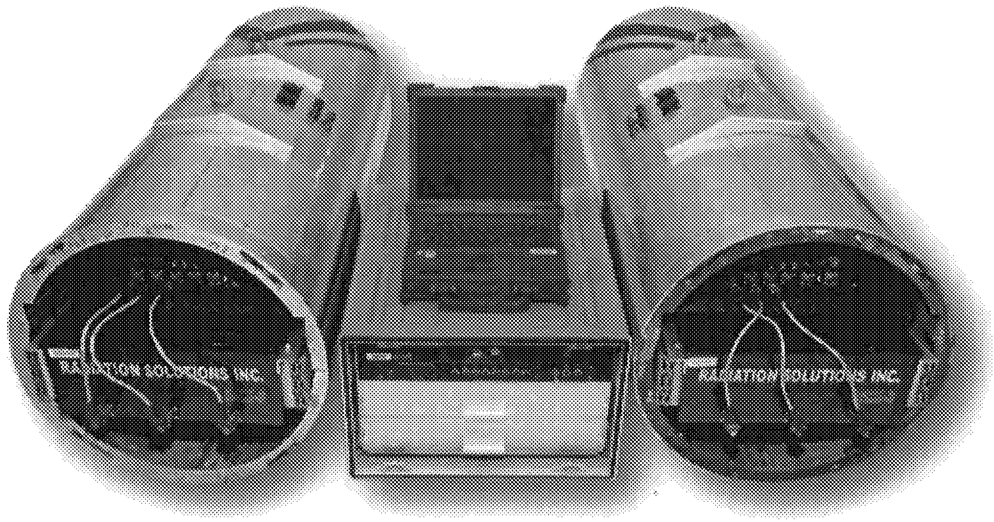


**Figure 3. The AMS-configured RSI radiation detection system.**

**The detector pods are shown with endcaps removed showing the RSI detectors inside. The Edak case in the center houses the RS-501 and power distribution panel. The laptop computer runs the system monitoring and data collection software.**

# 3 BACKGROUND RADIATION

Radiation is present everywhere in the environment from a variety of materials which include naturally-occurring sources and sources due to human activity. The normal level of radiation is known as background radiation and this varies from place to place, and to some extent from one time to another. Radiation is produced when a radioactive nucleus emits particles and/or gamma rays, a process known as radioactive decay. The total amount of particles and gamma rays at a particular spot can be measured as exposure rate in units of micro-roentgen per hour (μR/hr). The detectors used in the aerial survey are sensitive to gamma rays, and the number of gamma rays detected in a given time is known as the count rate, typically expressed as counts per second (cps). The detectors are calibrated to convert count rate to exposure rate.

The naturally-occurring sources include radioisotopes in the earth, radon in the atmosphere, and cosmic rays. Most radiation exposure comes from these natural sources. The natural radioisotopes in the earth produce what is called terrestrial radiation. These radioisotopes are primordial and their measurement is the primary goal of an aerial background survey. Human activities, such as construction and agriculture, can change the amount of natural radioisotopes present in a particular area. Radon is a radioactive gas formed by the decay of natural isotopes in the earth's crust. The amount of radon in the atmosphere at any given time depends largely on the weather. Cosmic rays originate from the sun and outside the solar system. The atmosphere and Earth's magnetic field provide shielding from cosmic rays, and so the number of cosmic rays present depends on altitude and latitude, with the number of cosmic rays increasing with increasing altitude and distance from the equator.

In the 1970s the governments of the United States and Canada conducted an aerial survey to map potassium, uranium, and thorium deposits in North America. Essentially all naturally-occurring terrestrial radiation comes from these sources. Figure 4 shows terrestrial gamma-ray exposure derived from this survey (Duval, Carson, Holman, & Darnley, 2005). The line spacing varied from 1 to 25 km, with most of the western United States flown with 5 km spacing. The United States Geological Survey (USGS) has made survey data available, and where there is significant overlap between the USGS survey and the AMS survey this data was used to calculate a terrestrial exposure rate for comparison (Grasty, Carson, Charbonneau, & Holman, 1984).

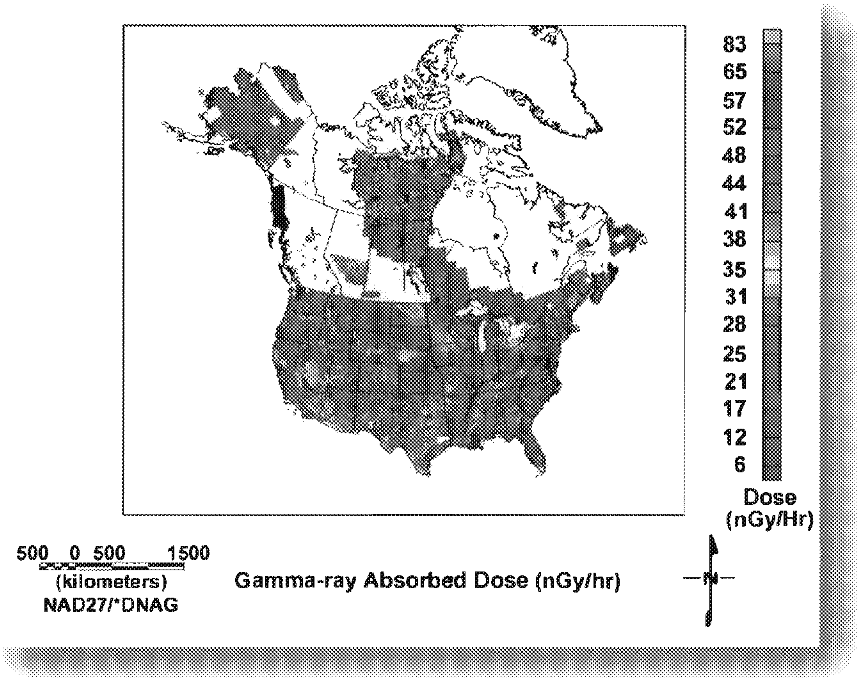


**Figure 4. U.S. Geological Survey map of terrestrial gamma-ray exposure.**

**Dose rates are given in nanogray per hour (nGy/hr). To convert to microroentgen per hour (μR/hr), divide the value in nGy/hr by 10. (Figure from (Duval, Carson, Holman, & Darnley, 2005))**

Human-created sources include medical isotopes, construction and industrial gauges, sterilization units, power generators, consumer products, and fallout from nuclear tests and accidents. The exposure rate from fallout from nuclear tests is very small, and is decreasing with time due to radioactive decay. Unless one is in close proximity to a nuclear power plant accident (e.g. Chernobyl or Fukushima), the exposure rate from these is also very small. The remaining sources are confined and strictly regulated. For example, radioactive sources used in industrial gauges must be shielded to prevent harmful exposure to anyone nearby.

# 4 DESCRIPTION OF SURVEY AREAS

Several discrete areas in the Bay Area were chosen for the survey. Criteria for selection included variability in terrain, geology, topology, and development. Areas were chosen that had been surveyed by a vehicle-mounted detection system, or could be surveyed by such a system. Selection was done in collaboration with the ARES program. The areas selected had a range of urban, suburban, and coastal environments.

For the purpose of the survey, each area was named for a prominent place name in the area. The areas were Oakland-Berkeley 1, Oakland-Berkeley 1A, Oakland Berkeley 2, Fisherman's Wharf, Alcatraz, Presidio, and Pacifica. In addition, a two-line survey was flown along the coast between Pacifica and Golden Gate, and is referred to as the Coastal survey. The survey areas are shown in Figure 5.

- Oakland-Berkeley 1 covered the area from roughly Alameda north to Berkeley Hills, and from the bay east to the University of California Berkeley campus and Piedmont. This area has dense residential and light industrial development.
- Oakland-Berkeley 1A covered the Outer Harbor. This area covers the port.
- Oakland-Berkeley 2 covered the area from Piedmont southeast to San Leandro, and consists of dense residential with some open space.
- Fisherman's Wharf covered the piers along the Embarcadero.
- Alcatraz covered Alcatraz Island, and was the only area completely surrounded by water.
- Presidio covered from Golden Gate on the north to Geary Boulevard on the south, and from Pacific Heights on the east to South Bay on the west.
- Pacifica gave a good contrast to the other areas with light residential development, coastline, and hilly topography.

At the request of the Department of Energy, Treasure Island, Yerba Buena Island, and Hunter's point were surveyed for the City of San Francisco and the California Department of Public Health. Data collected from these areas were not used by the ARES program. Because of the Bay Bridge, the helicopter could not fly at the required survey altitude over much of Yerba Buena Island; therefore only a few lines were flown over the southeastern tip of the island.

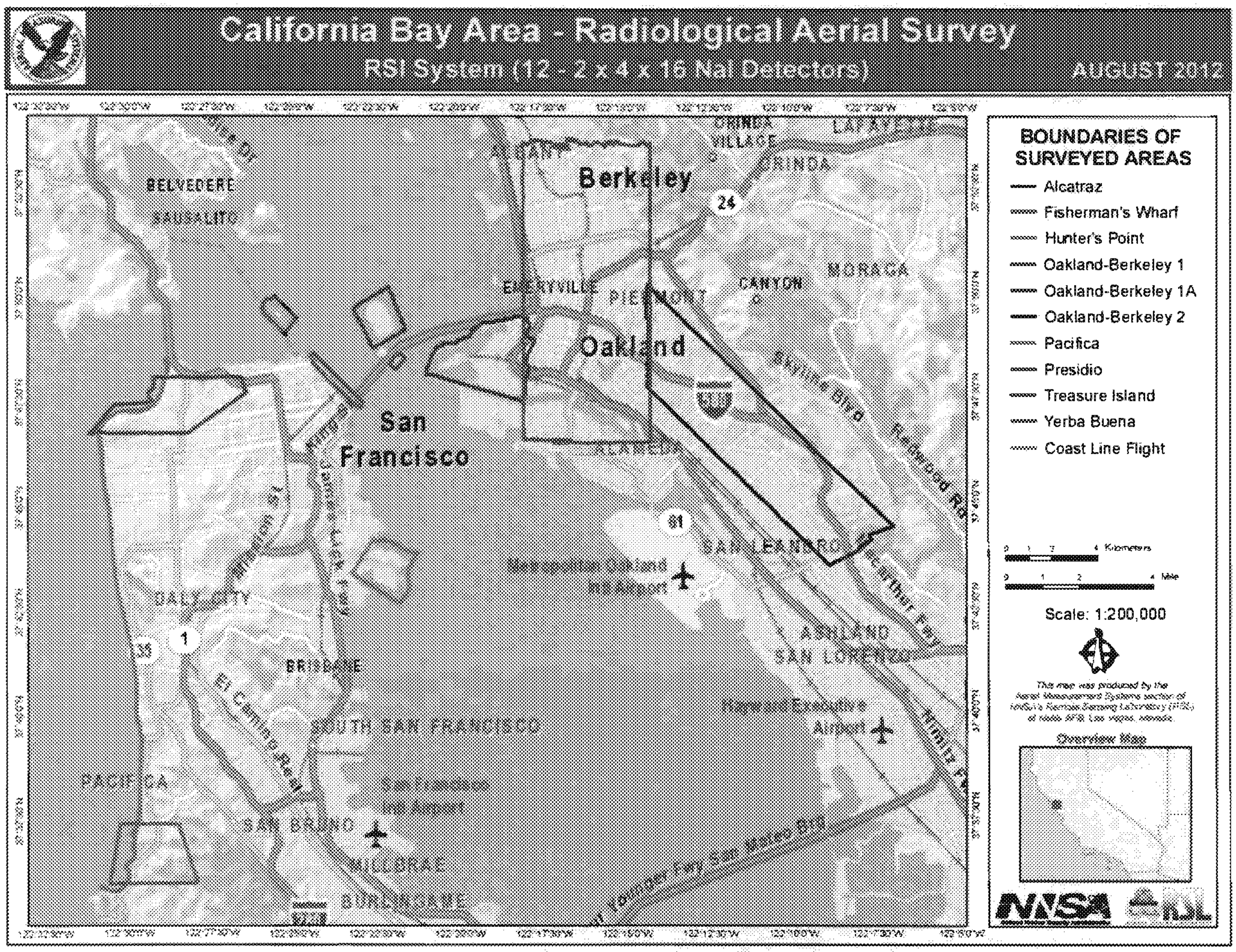


Figure 5. Areas selected for data collection during the Bay Area Survey.

# 5 SURVEY OPERATIONS

## 5.1 Fixed Base Operator

The survey was conducted out of the Hayward Executive Airport, which provided fuel and space for ground operations. This fixed base operator (FBO) was chosen for proximity to the survey areas and ease of access for the survey crew.

## 5.2 Daily Operational Checks

Every survey day, the radiation detection system and the data it collected were subjected to multiple operational and data quality checks. These checks ensured the quality of data both before and after collection.

### 5.2.1 Pre-Flight Checks

Prior to each day's flight, the detection system was turned on using ground power and its operation checked using both background and a small Cs-137 source. This initial morning check (known as a pre-flight) looked at detector response and calibration, as well as auxiliary system data (GPS and altimeter). All systems had to pass these checks before the helicopter was allowed to take off. On every survey day, the pre-flight checks showed the detector and auxiliary systems to be working normally.

### 5.2.2 Ground Data, Test Line, and Water Line

After the helicopter engines were started, but prior to take-off, the detector system was started and one minute of background data was taken on the ground. When the helicopter landed at the FBO following a survey flight, another minute of background data was taken. These background measurements were a check of detector consistency during the flight.

After take-off, the helicopter flew pre-determined lines at survey altitude over both land and water. The line flown over land (known as the test line) was over a taxiway at Hayward Executive Airport, and served as an additional consistency check on the data. Unlike the ground data, which were taken at a fixed location, test line data were taken at survey altitude and speed over an area of varying background. The test line data were examined for consistency from flight to flight along the length of the line. Any variations outside of those expected from normal fluctuations would be cause to examine the detector system for inconsistencies. No such variations were found during the survey.

The line flown over water (known as the water line) was also flown at survey altitude and speed. The location of the line was over San Francisco Bay. Because there is no terrestrial radiation over the water line, data collected here has contributions from only cosmic rays, radon, and the aircraft. These data are subtracted from data collected over the survey areas, yielding an excellent measurement of count rates due to only terrestrial radiation. Aircraft and cosmic ray backgrounds are essentially constant during the survey, but because of daily fluctuations in atmospheric radon concentrations small variations were seen in the water line count rates from day to day. However, because the water line was flown every flight, these data provided an adequate subtraction of non-terrestrial radiation.

After the helicopter completed each survey flight, the water and test lines were flown again at survey altitude and speed before it returned to the FBO. These lines provided an important consistency check on the data. If the water line data showed an abnormal variation in the pre-survey and post-survey data this could generally be attributed to a changing level of radon in the atmosphere. If this were the case, the water line rate subtracted from the survey data would be found by linearly extrapolation between the pre-survey and post-survey water line rates.

### 5.2.3 Post-flight Checks

Following each survey flight, data were downloaded from the helicopter and analyzed for data quality. Consistency in the data (count rate, spectral shape, etc.) was checked for the duration of the flight. GPS and altimeter data were also checked for consistency and completeness.

## 6 AMS DATA ANALYSIS

Using AMS-developed techniques and software, data are analyzed and presented as contour maps using commercial GIS software. Data can be viewed in several ways, each taking advantage of and highlighting some specific aspect of the survey. A gross count map shows the total count rate, corrected for non-terrestrial contributions (radon, cosmic, and aircraft) at survey altitude. The exposure rate map takes the gross count map and converts into a map of exposure rate at one meter above the ground using conversion coefficients derived from the altitude spiral flown at Hayward Executive Airport and flights at the Lake Mohave, NV, calibration range. Because the conversion from gross counts to exposure rate can be reduced to a simple multiplicative factor, gross counts and exposure rates are shown on the same map.

## 6.1 Gross Count Analysis

The radiation detection system counts gamma rays that arrive at the detector, regardless of the source of the gamma rays or their history. Gamma rays originate from the ground, radon (in the air), cosmic rays, equipment surrounding the detector, and the flight crew. The count rate from radon, cosmic rays, equipment, and crew is essentially constant during a survey flight, and must be subtracted from the raw count rate. The remaining count rate is assumed to come from the ground, and is the count rate of interest. Before they reach the detector, gamma rays from the ground must travel though several hundred feet of air, which interacts with and attenuates the gamma rays. Count rates are normalized to the nominal survey altitude with the following equation:

$$GC = (RC - BC)e^{-(SA-MA)\mu}$$

where

$GC$ = corrected gross count rate
$RC$ = raw count rate
$BC$ = background count rate from radon and equipment
$SA$ = nominal survey altitude of 300 feet above ground level
$MA$ = measured altitude
$\mu$ = attenuation factor

The nominal survey altitude is the desired flight altitude, which for this survey was 300 feet above ground level. The measured altitude is determined from the on-board radar altimeter. The air attenuation factor $\mu$ is derived from the altitude spiral flown over the test line at Hayward Executive Airport. During flight, the helicopter's altitude above ground will vary by about ten percent from the desired survey altitude. This technique effectively normalizes the count rate from terrestrial sources to the count rate measured at the nominal survey altitude of 300 feet above ground level.

The resulting corrected gross count rates are then displayed as a contour plot superimposed over a map or image of the survey area. Doing this analysis allows the display of count rate due to only terrestrial sources and removes changes in the count rate due to variations in helicopter altitude.

## 6.2 Exposure Rate Algorithm

Once the corrected gross count rate is determined, it can be converted into a terrestrial exposure rate with the use of a conversion factor. The conversion factor takes the count rate at 300 feet above ground level from the survey and converts it to an exposure rate in micro Roentgen per hour (μR/h) at three feet above ground level. The conversion factor was determined from calibration flights made at the Lake Mohave Calibration Range in Clark

County, NV, and the air attenuation factor from the altitude spiral flown at Hayward Executive Airport.

The Lake Mohave calibration flights give the conversion from count rate at 300 feet AGL to exposure rate at three feet AGL at the calibration range. Because of the elevation difference between the calibration range and the Bay Area there is also an atmospheric pressure difference that needs to be accounted for. This pressure difference changes the amount of attenuation gamma rays experience between the ground and the air-borne detector. Since the air attenuation factor was measured at Hayward Executive Airport, it can be used to modify the Lake Mohave calibration factor to make it appropriate for use in the Bay Area.

The conversion from corrected gross count rate to exposure rate is simply the following equation:

$$ER = \frac{GC}{CF}$$

where

$ER$ = exposure rate at three feet AGL in μR/h
$GC$ = corrected gross count rate in counts per second (cps)
$CF$ = conversion factor

For the Bay Area Survey the conversion factor was the following:

$$CF = 1808 \frac{\text{cps}}{\mu\text{R/h}}$$

Because of the linear relationship between corrected gross counts and exposure rate, both quantities can be displayed on the same contour plot using the same color levels.

# 7 STATISTICS

An overview of all the data collected can be had by looking at average corrected gross count rates for each survey area. This can give some guidance on what to expect when looking at the contoured data. Table 1 lists the number of data points, the minimum and maximum corrected gross count rates, the average corrected gross count rate, and the standard deviation of the corrected gross count rates for all survey areas. Only data points which were over land areas were included in the table.

Figure 6 displays the average count rates of all surveyed areas. The average of the average rates for all areas is 4150 ± 650 cps. The frequency of average count rates is shown in a bar chart on the right side of the figure. Pacifica shows the largest standard deviation in count rate, reflecting the large range of count rates measured. Oakland-Berkeley 1 has a larger count rate range, but its exposure rate distribution is concentrated symmetrically around the average, compared to the much broader and asymmetric Pacifica distribution. The corrected count rate distributions from Oakland-Berkeley 1 and Pacifica are shown in Figure 7, illustrating the difference in the shapes of the distributions that lead to the difference in standard deviations.

**Table 1. Corrected gross count rate statistics for all survey areas.**

| Area | Number of Data Points | Minimum Rate [cps] | Maximum Rate [cps] | Average Rate [cps] | Standard Deviation of Average Rate [cps] |
|---|---|---|---|---|---|
| Alcatraz | 24 | 2105 | 4180 | 3534 | 478 |
| Hunter's Point | 828 | 2200 | 6992 | 4372 | 829 |
| Oakland-Berkeley 1 | 23526 | 512 | 13912 | 4514 | 875 |
| Oakland-Berkeley 1A | 2075 | 1693 | 6011 | 3691 | 638 |
| Oakland-Berkeley 2 | 13085 | 1359 | 8968 | 4257 | 859 |
| Pacifica | 2017 | 933 | 11430 | 4069 | 2129 |
| Presidio | 2970 | 3149 | 9690 | 5278 | 1182 |
| Treasure Island | 434 | 2774 | 5947 | 4604 | 672 |
| Fisherman's Wharf | 51 | 1078 | 4244 | 2926 | 906 |
| Yerba Buena Island | 32 | 3234 | 6321 | 4227 | 548 |

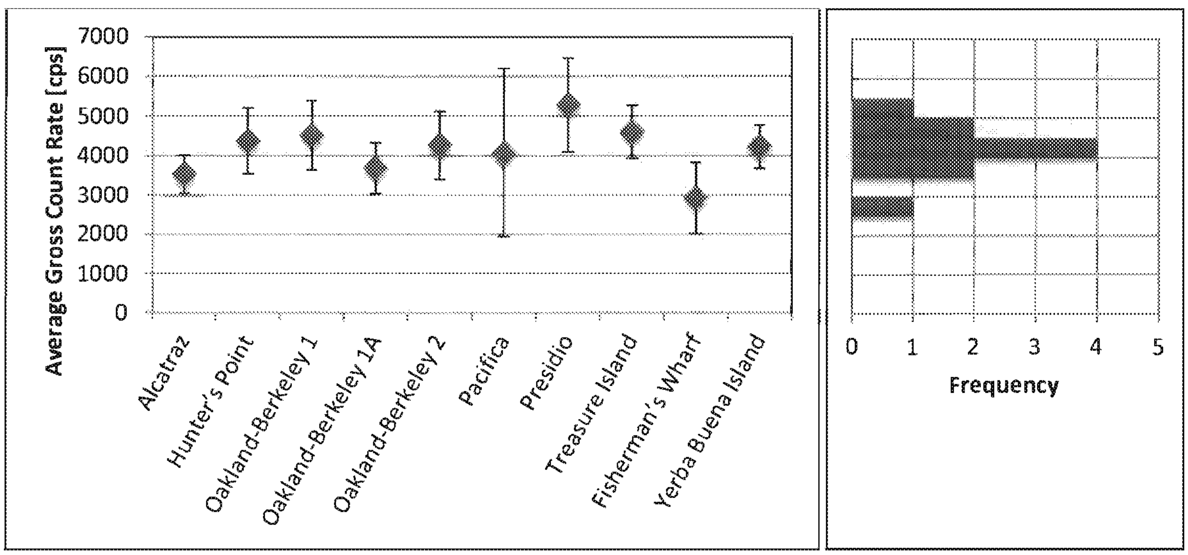


**Figure 6. Average corrected gross count rates.**

**The average corrected gross count rates for each survey area are shown on the left. Error bars are standard deviations of the averages. On the right is a histogram showing average gross count rate frequency per 500 cps.**



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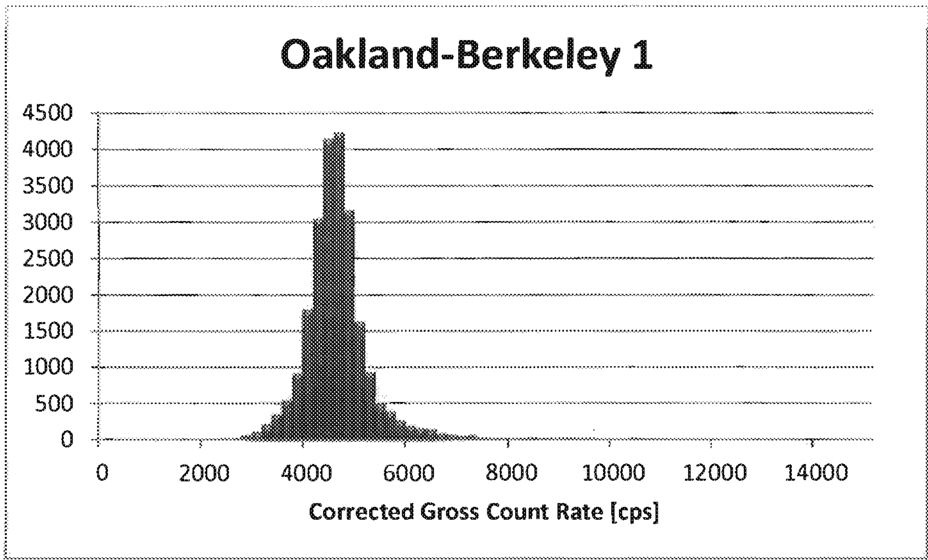


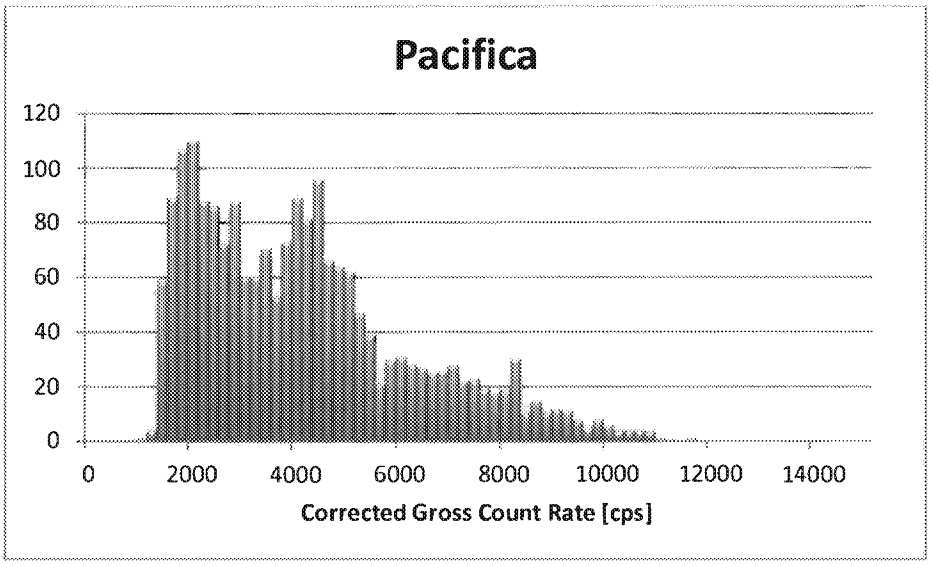




**Figure 7. Corrected gross count distributions for Oakland-Berkeley 1 and Pacifica.**

**The Oakland-Berkeley 1 distribution, although having the larger range, is more concentrated around its average than the Pacifica distribution.**

# 8 AERIAL SURVEY RESULTS

Results are presented here as contour maps of corrected gross counts and exposure rates. The radiation level scales on the maps of different areas use the same break points, but only levels present in a given map are shown in its legend.

The gross count and exposure rate contour maps are presented below. As discussed above, the conversion from gross counts to exposure rate is a simple multiplicative constant, so both can be shown on a single map by simply renaming the contours. When this was done, exposure rate levels were rounded to the nearest tenth of a μR/hr. The USGS exposure rate map in Figure 4 indicates terrestrial exposure in the Bay Area is expected to be in the range of about 2.5 – 5 μR/hr. Data collected during the AMS survey compare favorably with that span.

The Oakland-Berkeley 1 area is shown in Figure 8. Exposure rate values over land are, in general, in the range 1.4 – 4.3 μR/hr. A relevant feature to note is the very low count and exposure rates over areas of water. This is because it is the terrestrial radiation being mapped, after correction for cosmic, radon, and aircraft rates. This is a feature typical to all surveys. Also of note are the relatively high rates toward the northeast of this area, going up to 12.2 μR/hr. This difference between this section and other sections of lower count rate is primarily due to the geology of the hills in that area and is well within normal background radiation fluctuations. Certain roads stand out having a higher or lower count rate than adjacent areas. This is also a common occurrence caused by materials used to construct the roads having been trucked in from another area.

The average terrestrial exposure rate for this area is 2.50 ± 0.48 μR/hr. Two lines from the USGS survey (Section 3) crossed this area, and the exposure rate calculated from those lines is 2.23 ± 0.44 μR/hr.

The highest gross count rate in this area occurs at about latitude 37° 51.866', longitude -122° 14.273 (circle 1 in Figure 8). A spectrum was extracted from this area is displayed in Figure 9 along with a spectrum (corrected for collection time) from a nearby area with low gross count rate. The shapes of the spectra are nearly identical, indicating the high count rate is due to elevated natural background. The reason for this elevated rate could be difference in geology of this region, or it could be because this region is relatively undeveloped compared to the rest of the survey area, and the ground is unshielded by construction materials.

Several anomalous signals were detected in this area (circles 2 – 4 in Figure 8), which were all determined to be consistent with radioisotopes used in nuclear medicine. Detections of this type are common in populated areas. Spectra from these anomalies are displayed in Figure 10 through Figure 12.

Oakland-Berkeley 1A is shown in Figure 13. Normal fluctuations are seen in this area, with perhaps some indication of slightly elevated rates over the railroad yard in the southeast corner. This is also common occurrence, caused by the rock used in the rail bed.

Oakland-Berkeley 2 is shown in Figure 14. This area also shows normal variations, with the largest count rates probably caused by changes in geology.

Survey results from Presidio are shown in Figure 15. Exposure rates measured in these areas, 1.4 - 4.3 μR/hr, also compare well with those reported by USGS.

The gross count contour map from Pacifica is shown in Figure 16. Exposure rates measured in this area are within the normal range. The map shows typical variations due to geology and differences in development. The average exposure rate for this area is 2.25 ± 1.18 μR/hr. A single line from the USGS survey (Section 3) crossed this area, and the exposure rate calculated from that line is 1.67 ± 0.83 μR/hr.

Alcatraz is shown on Figure 17. Results are as expected for a small island. Because the detection footprint (the area measured in one second by the helicopter) is a significant fraction of the size of the island, the water-land boundary is not clearly seen. This is a typical effect, and can be seen along other coastal areas.

Results from Fisherman's Wharf are shown in Figure 18. Interesting things to note here include the elevated count rate shown by the Bay Bridge, a result of the construction materials used standing out against the very low background rate of the water. Exposure rates are well within the normal range and these show nothing unusual.

Treasure Island is shown in Figure 19. As with Alcatraz, because of the size of the effective detection area, there is no sharp demarcation of the shoreline. Spectra from the highest count rate area (3.0 – 4.3 μR/hr) are displayed in Figure 20 to Figure 22. These spectra are consistent with higher natural background due to normal variations.

Yerba Buena Island is shown in Figure 23. Because of the Bay Bridge, only a few lines were flown here.

Hunter's Point is shown in Figure 24. This small peninsula shows the same shoreline effect as Alcatraz and Treasure Island. The spectrum from the highest count rate region (3.0 – 4.3 μR/hr) is shown in Figure 25. The high count rate here is due to more potassium-40 (a naturally-occurring radioisotope) here than other places on the peninsula.

# 9 SUMMARY

The data collected during the aerial radiological survey of the Bay Area are of good quality and pass all validation tests. Analysis of this data shows expected variations in normal background count rates. Several medical isotopes were identified, which is a common occurrence in a survey such as this.

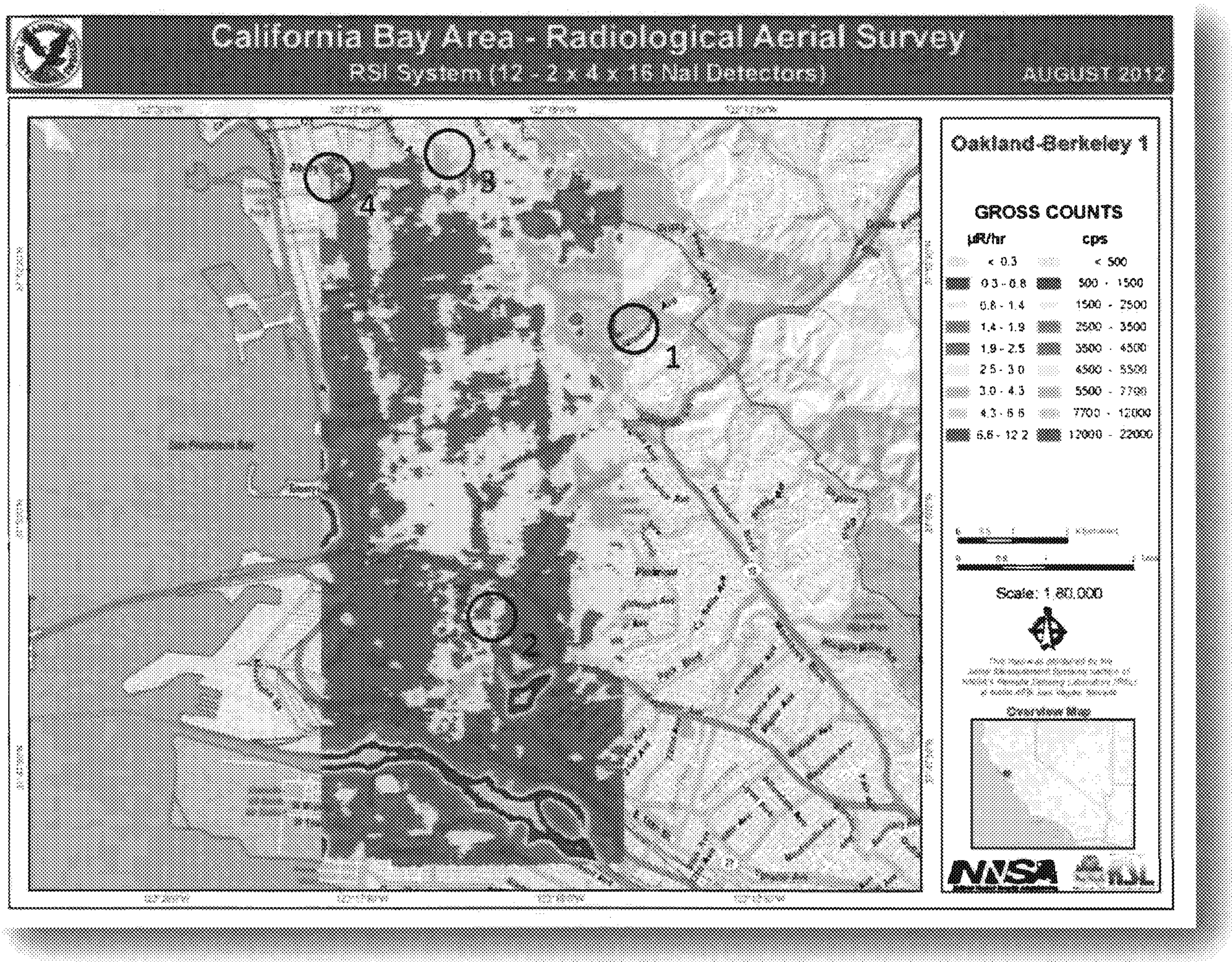
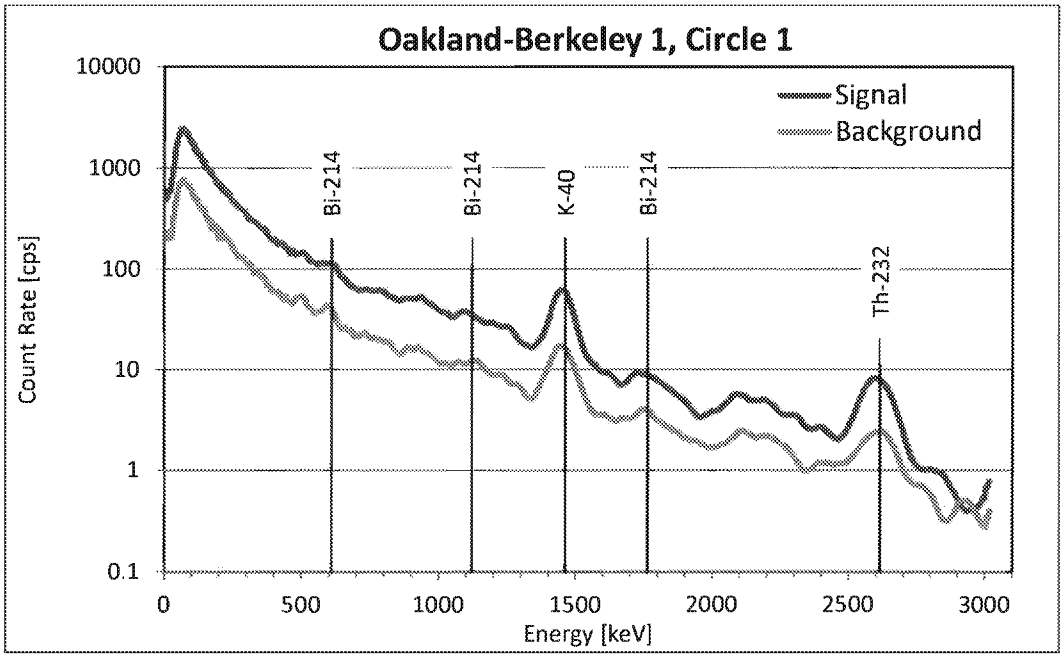



**Figure 8. Oakland-Berkeley 1 gross count and exposure map.**

**The high gross count rate at about latitude 37° 51.866', longitude -122° 14.273 (circle 1) is elevated natural background. Anomalous signals found in areas marked by circles 2 – 4 were determined to be medical isotopes.**



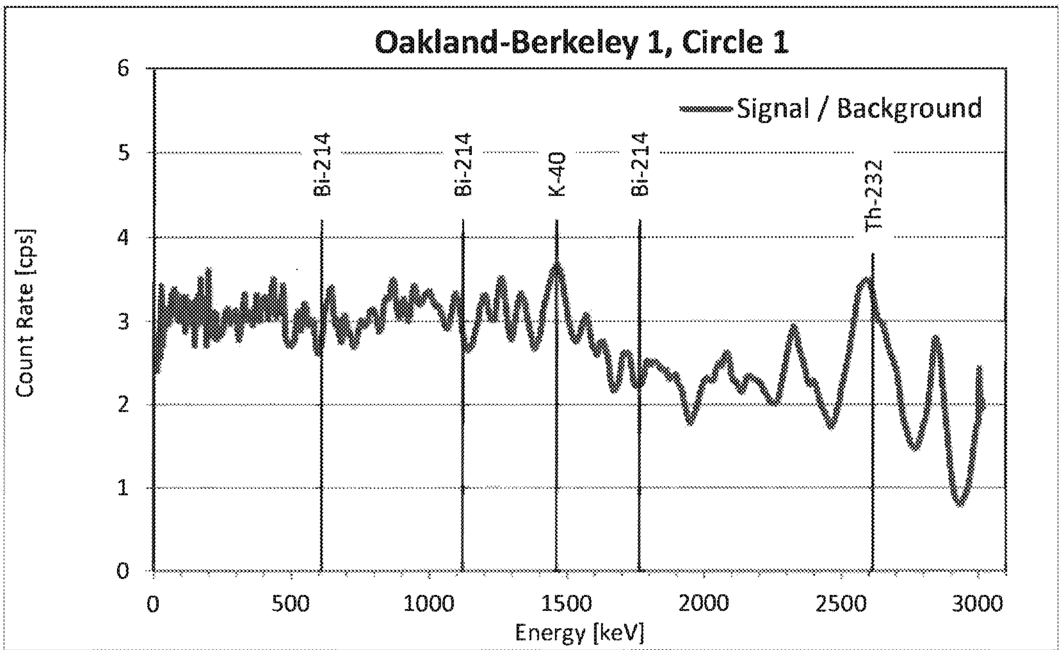




**Figure 9. Spectrum from the Oakland-Berkeley 1 survey area.**

**The upper plot shows the spectrum taken at circle 1 in Figure 8 (blue trace) and a spectrum taken from a nearby area (green trace), corrected for collection time. The spectra have essentially the same shape, indicating the higher count rate is due to an elevated level of natural radiation. The ratio is shown in the lower plot, and is essentially constant below 1500 keV, indicating the difference in count rates is due to differing levels of background radiation. Marked peaks are from naturally-occurring radioisotopes.**

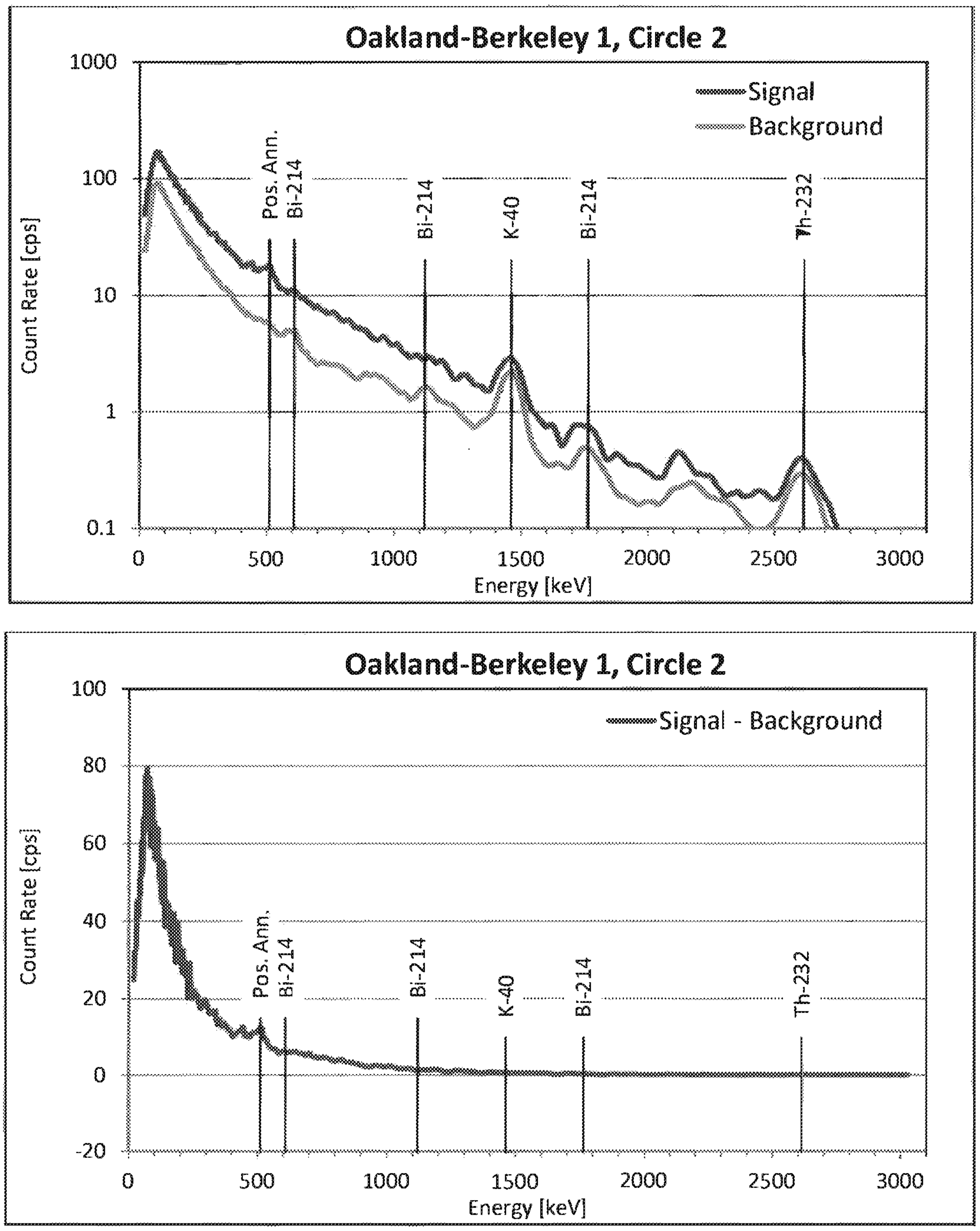



**Figure 10. Spectrum from the Oakland-Berkeley 1 survey area.**

**The spectrum was taken at circle 2 in Figure 8. The blue trace in the upper plot is the spectrum of the anomaly and the green trace is a background spectrum collected nearby. Spectra are real time normalized. The excess counts below about 1500 keV are consistent with a medical facility. The peak at 511 keV is likely due to positron emission from fluorine-18, a commonly used medical isotope.**

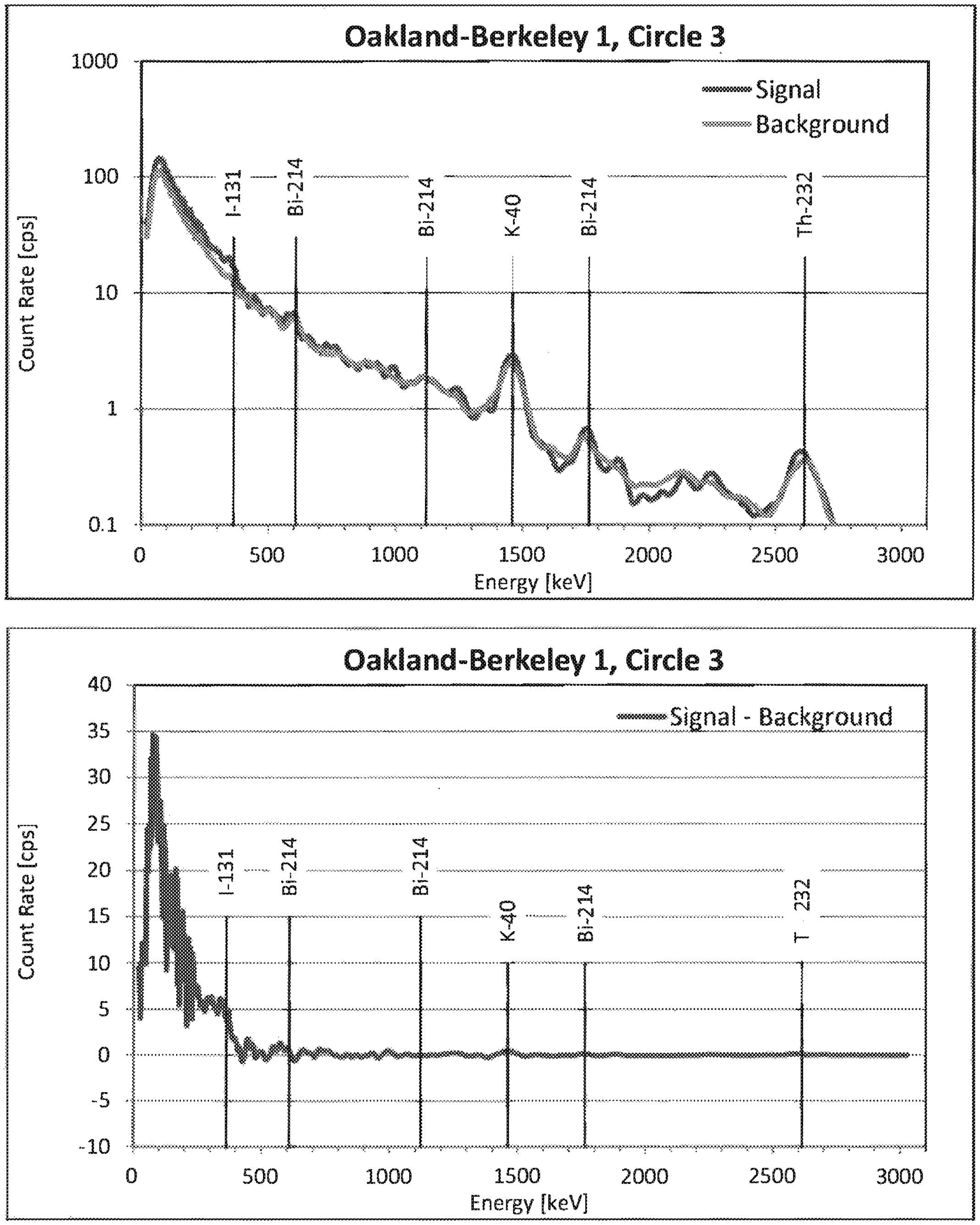
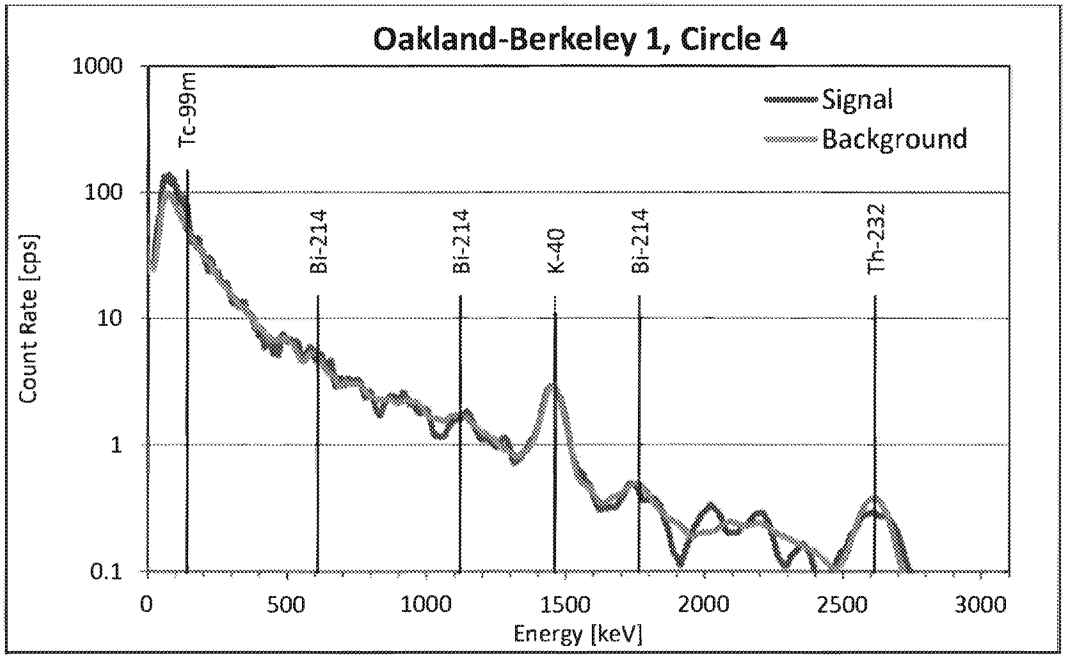



**Figure 11. Spectrum from the Oakland-Berkeley 1 survey area.**

**The spectrum was taken at circle 3 in Figure 8. The blue trace in the upper plot is the spectrum of the anomaly and the green trace is a background spectrum collected nearby and corrected for collection time. The lower plot is the difference between the spectra. The background has been normalized by total counts above 1364 keV. The peak at about 364 keV is consistent with gamma emission from iodine-131, a commonly used medical isotope. The excess counts below this peak are caused by gammas originally at the peak energy that have lost part of their energy through interactions in material between the source and the detector.**



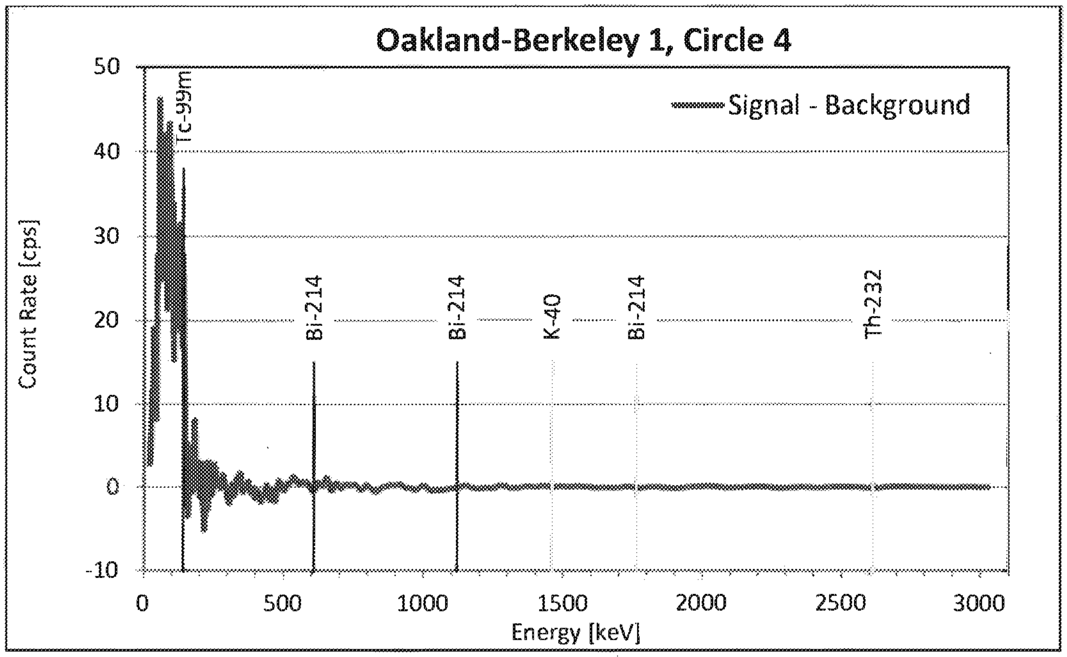




**Figure 12. Spectrum from the Oakland-Berkeley 1 survey area.**

**The spectrum was taken at circle 4 in Figure 8. The blue trace in the upper plot is the spectrum of the anomaly and the green trace is a background spectrum collected nearby and corrected for collection time. The lower plot is the difference between the spectra. The background has been normalized by total counts above 1364 keV. The peak at about 141 keV is consistent with gamma emission from technicium-99m, a commonly used medical isotope. The excess counts below this peak are caused by gammas originally at the peak energy that have lost part of their energy through interactions in material between the source and the detector.**

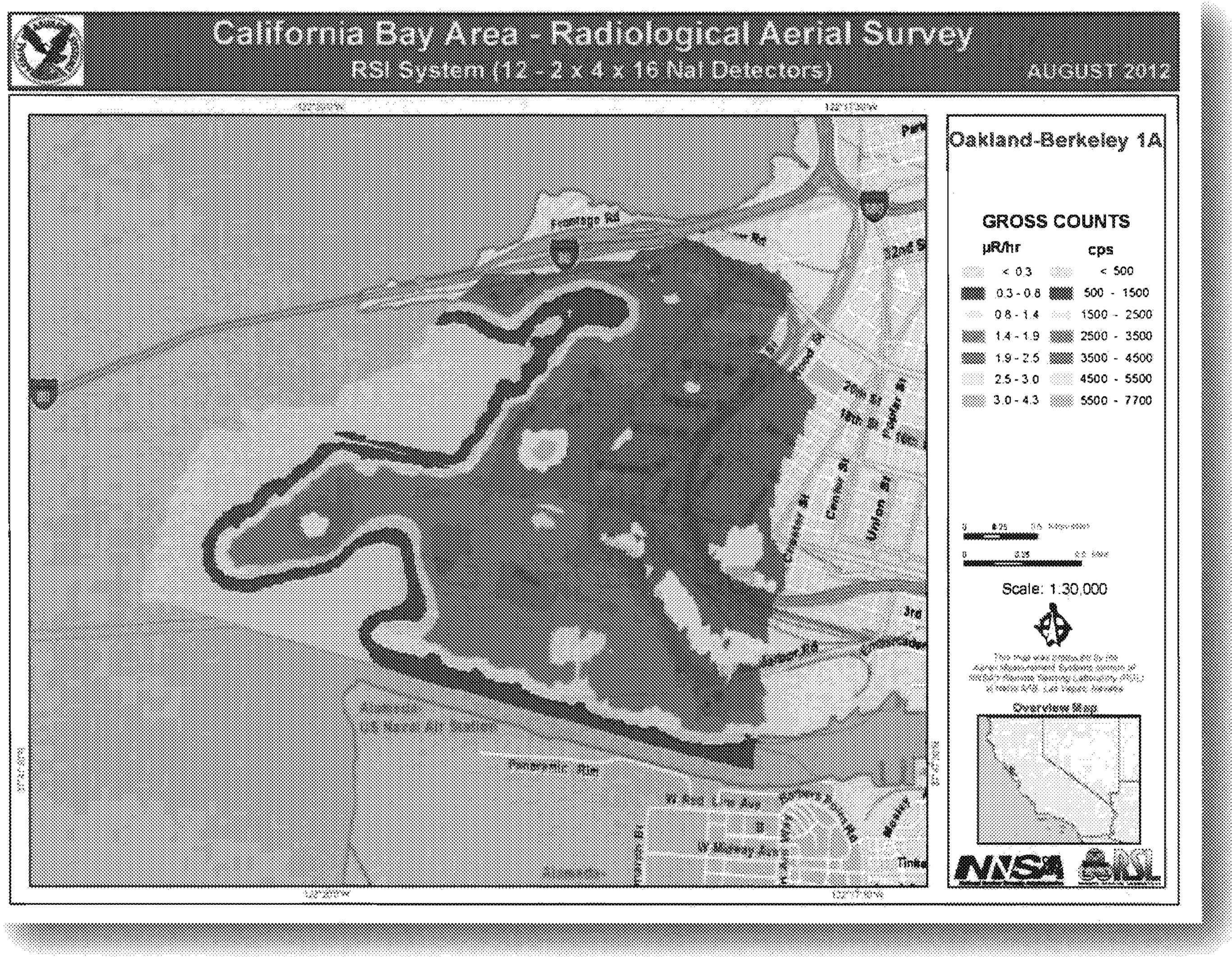



Figure 13. Oakland-Berkeley 1A gross count and exposure map.

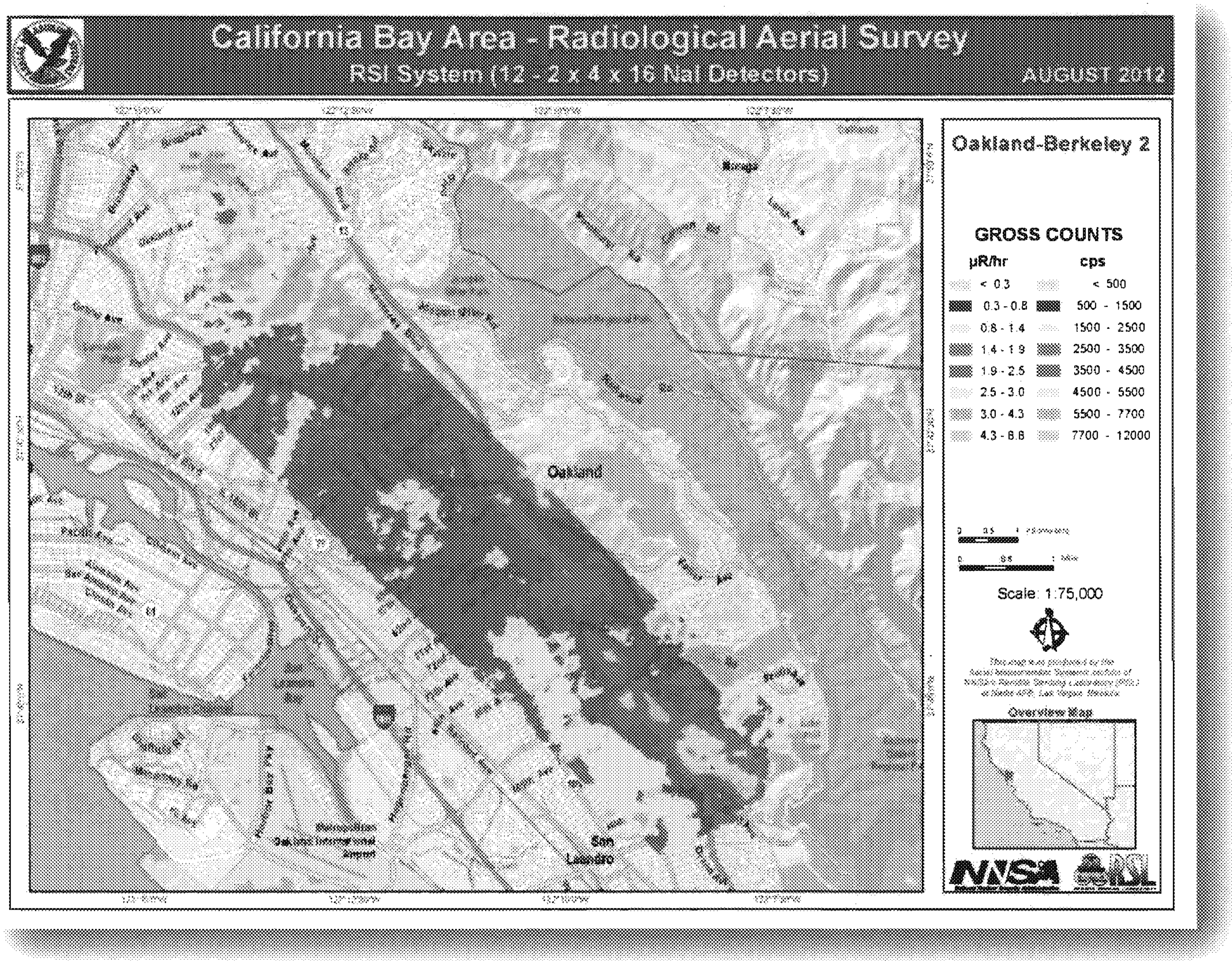



Figure 14. Oakland-Berkeley 2 gross count and exposure map.



ED_002145A_00003887-00034

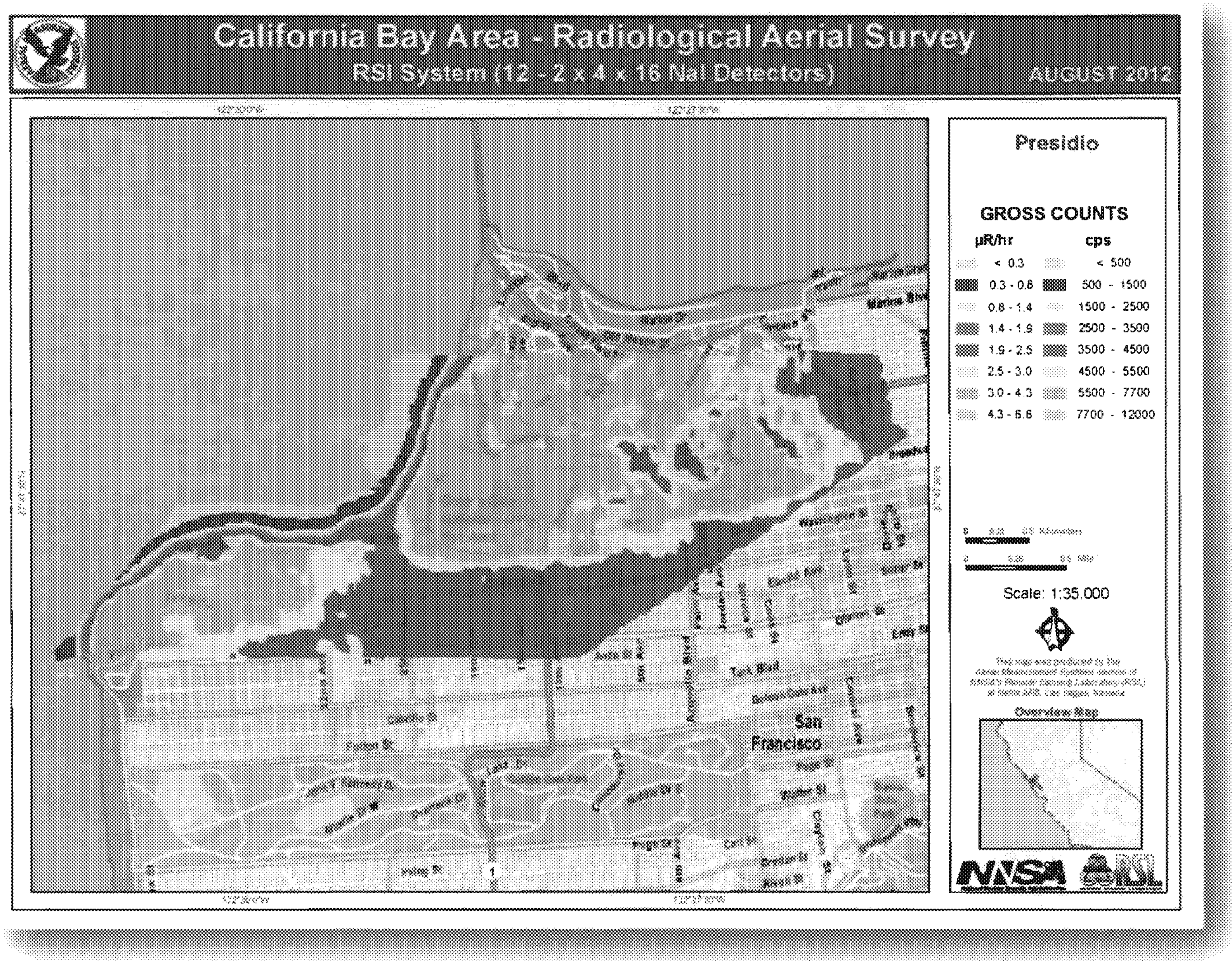



Figure 15. Presidio gross count and exposure map.



ED_002145A_00003887-00035

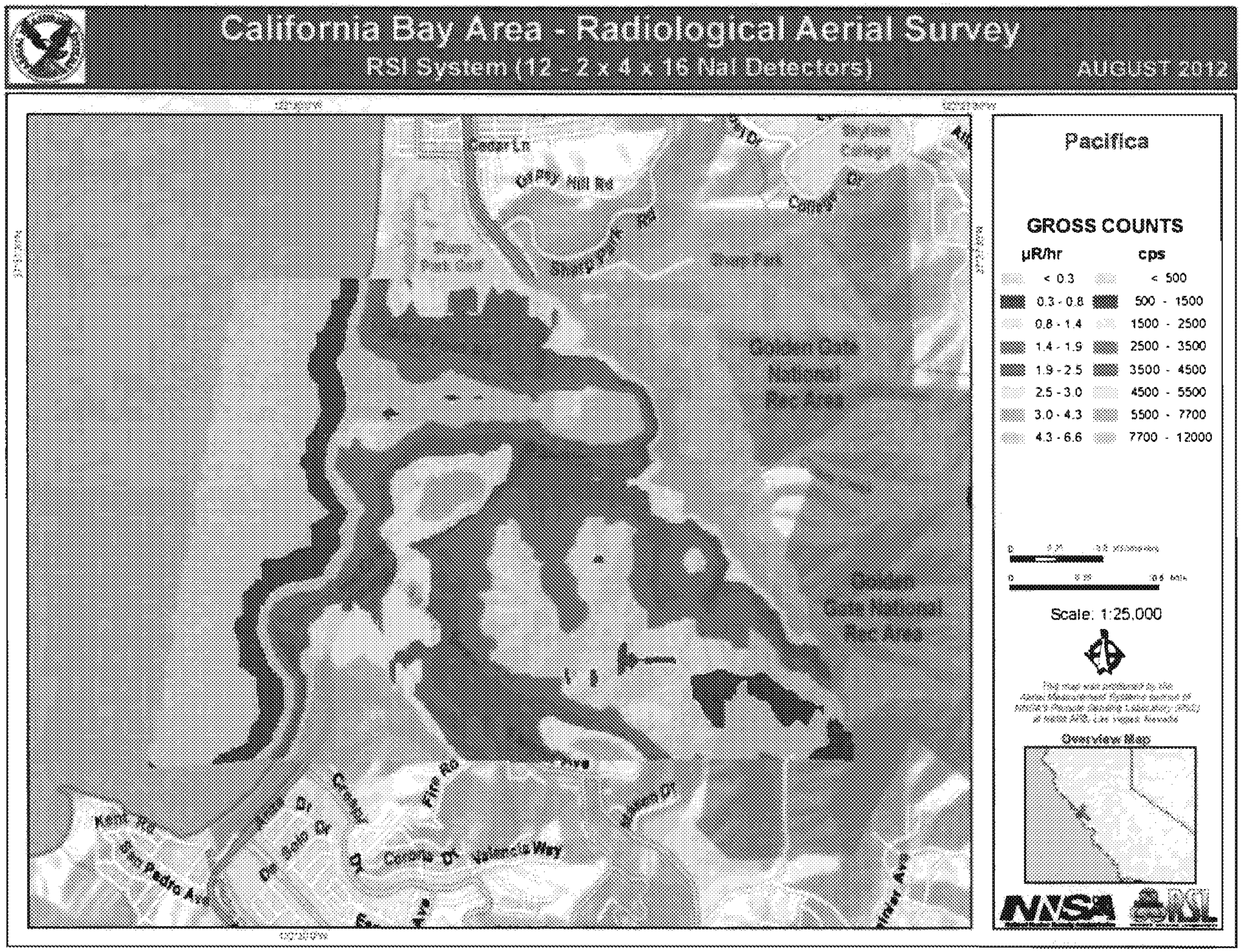



Figure 16. Pacifica gross count and exposure map.

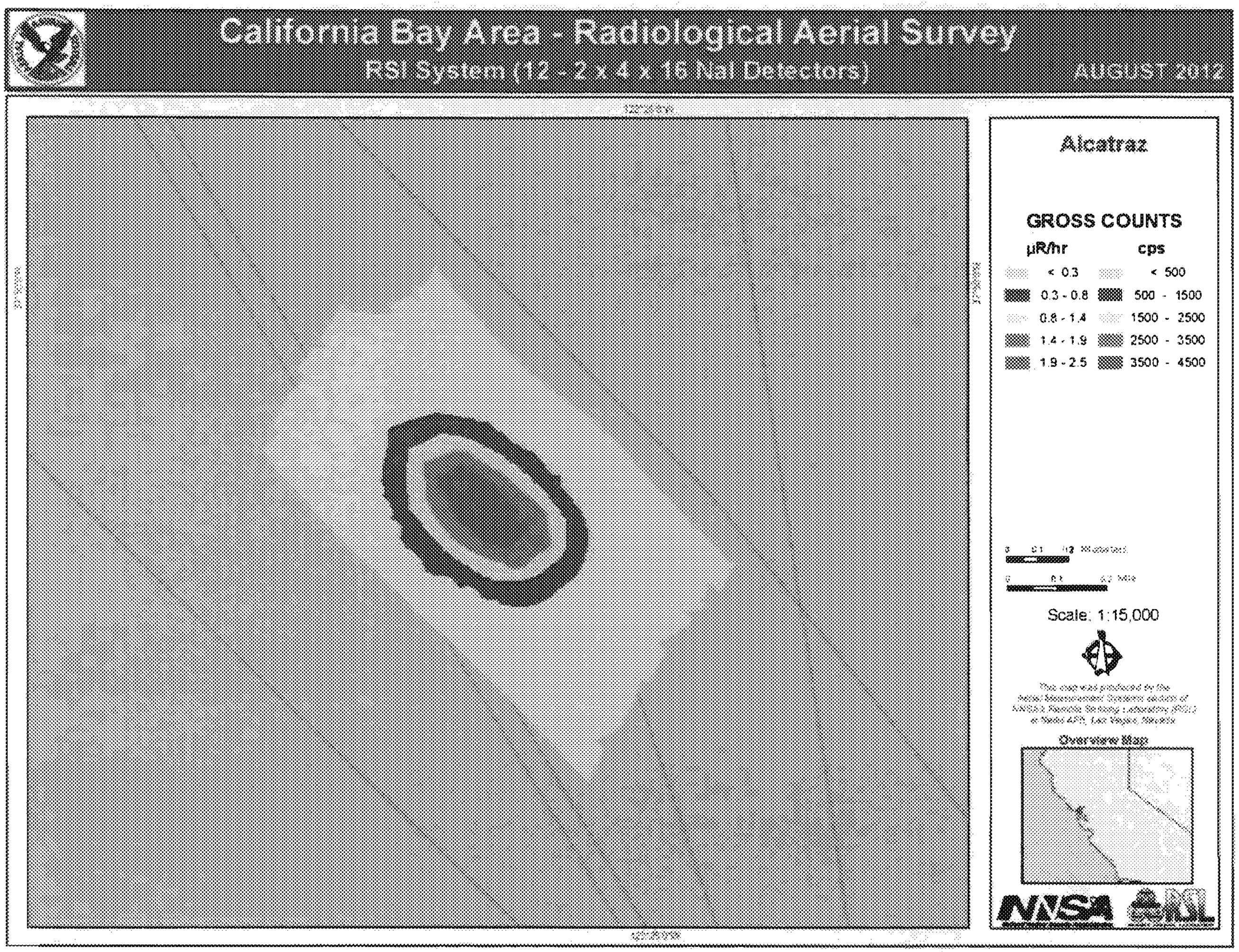



Figure 17. Alcatraz gross count and exposure map.

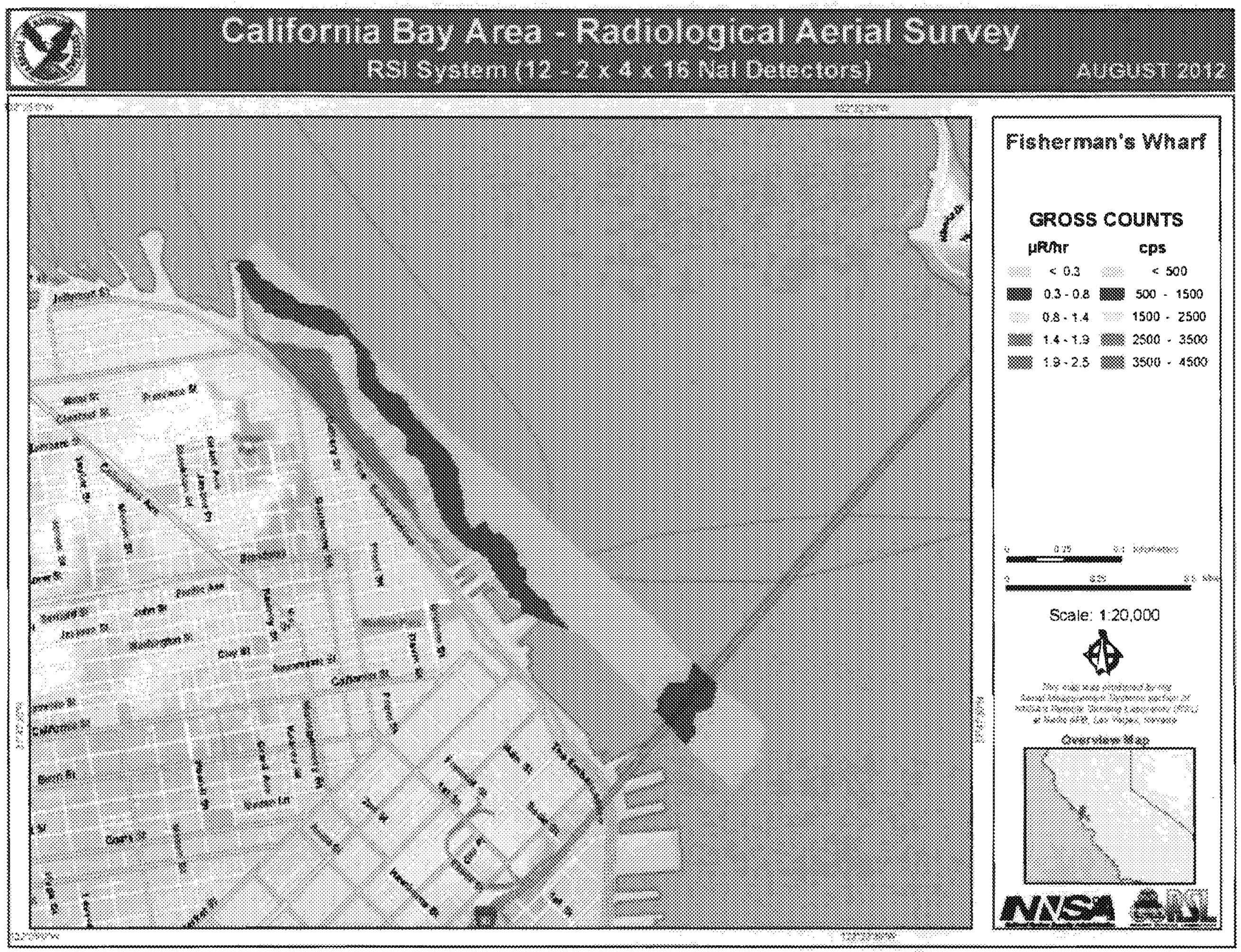



Figure 18. Fisherman's Wharf gross count and exposure map.

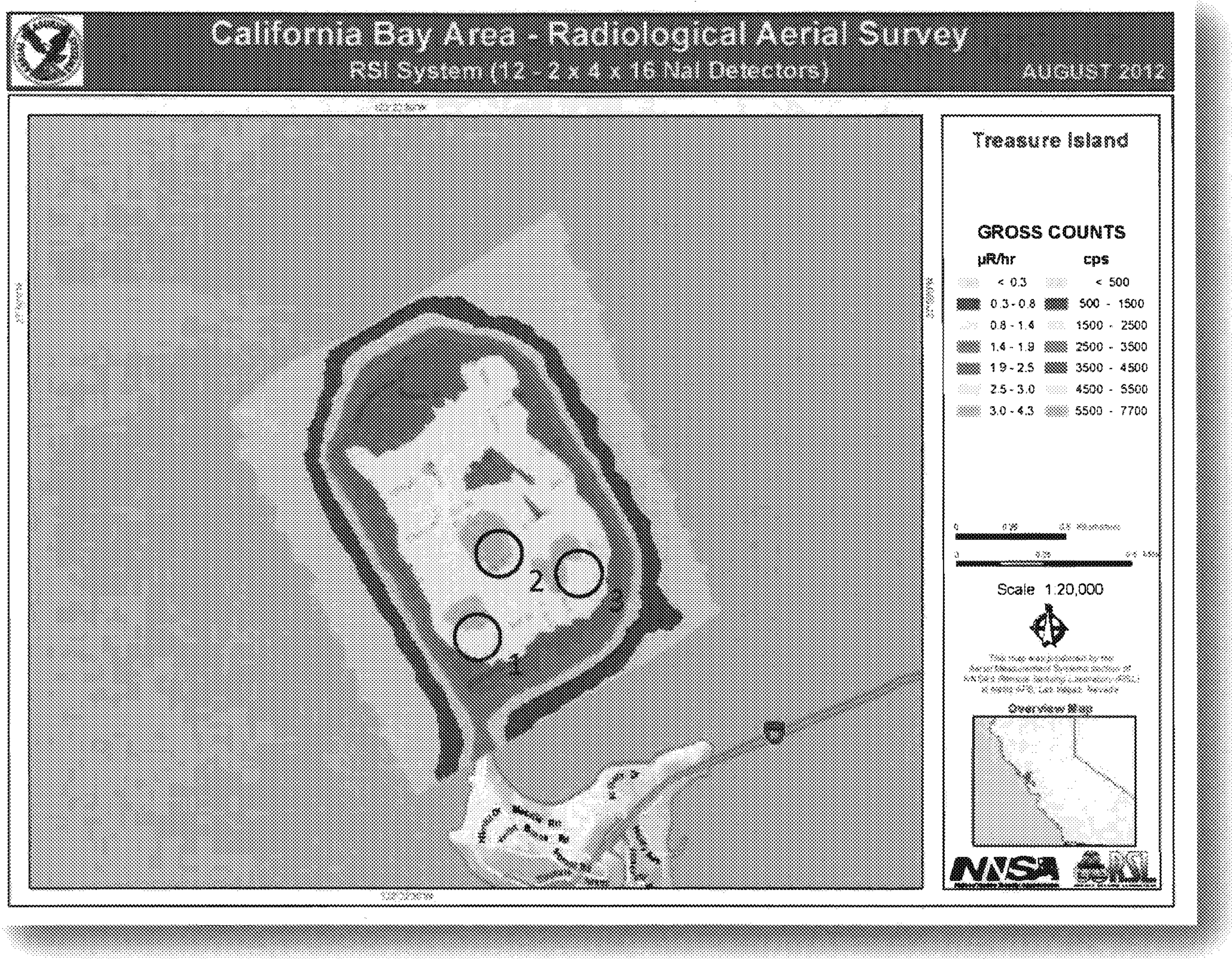
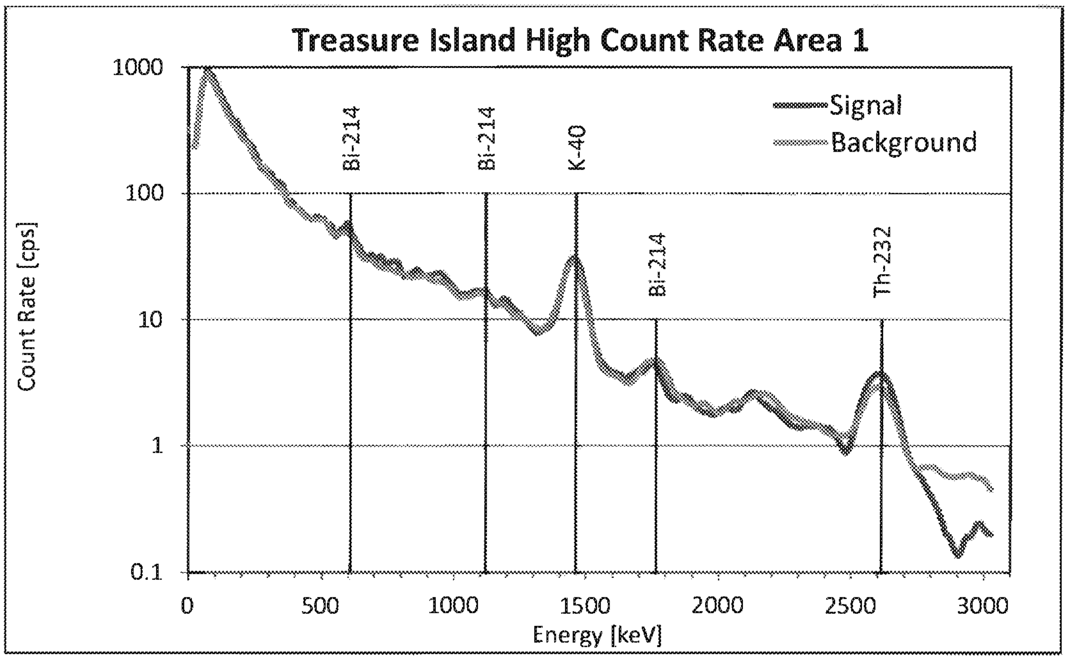



Figure 19. Treasure Island gross count and exposure map.

The circles indicate areas of highest corrected gross count rate. The spectra from these areas are shown in following figures.



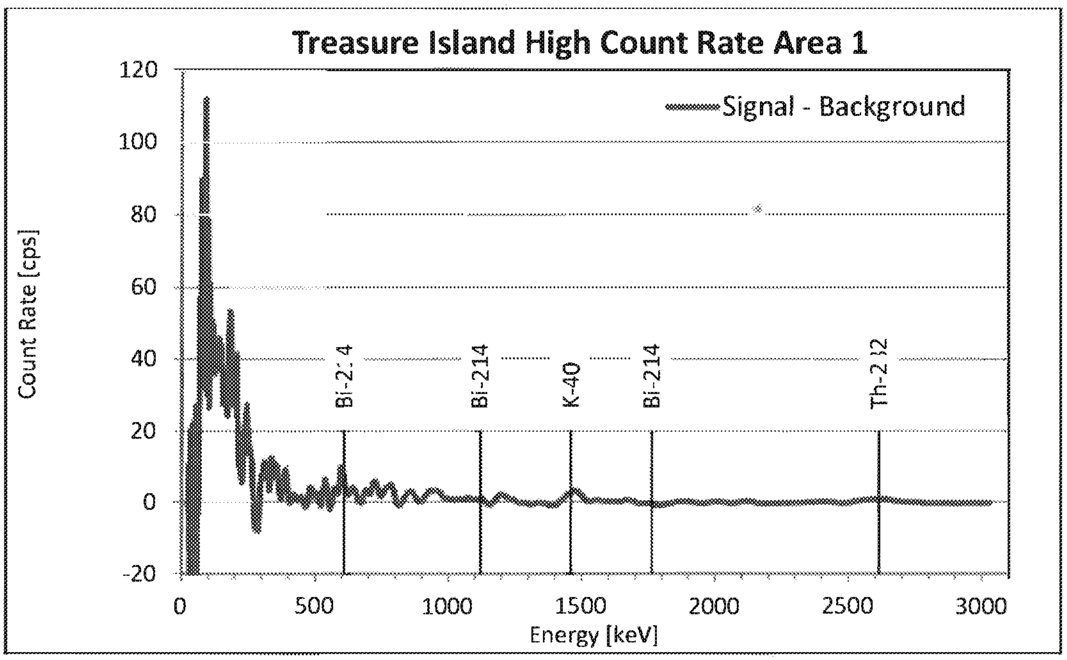
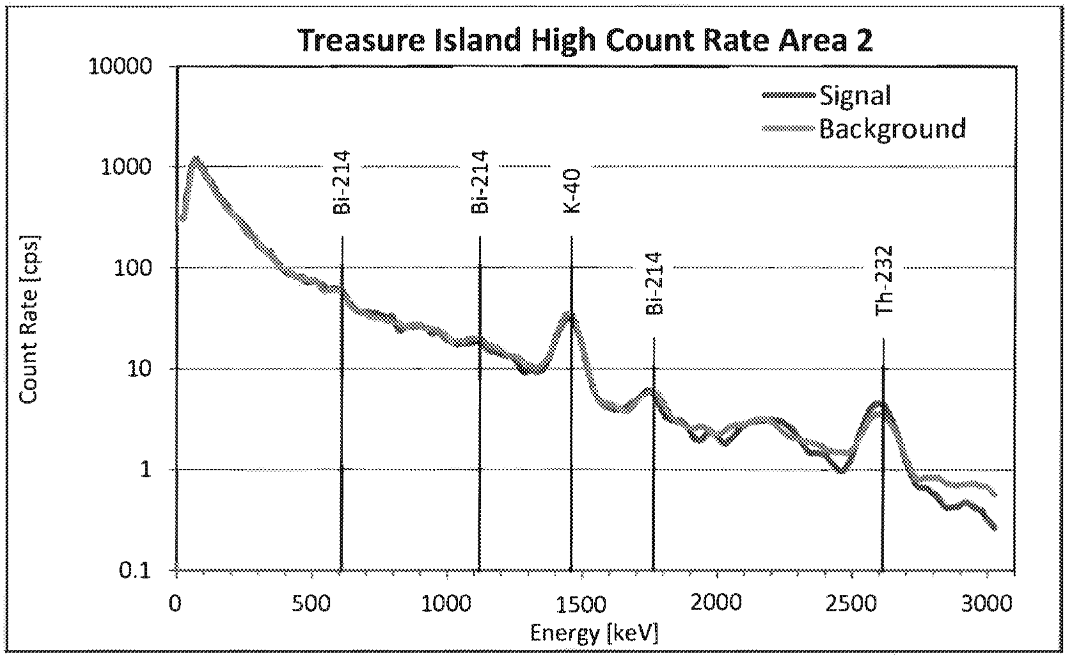




**Figure 20. Spectrum from Treasure Island high count rate area 1.**

**The upper plot shows the spectrum from the area marked by circle 1 in Figure 19 (blue trace) and a background taken from the northern part of the island normalized by total counts above 2500 keV (green trace). The lower plot shows the difference between the signal and background from the upper plot. The result is consistent with no excess radioisotopes. Marked peaks are from naturally-occurring radioisotopes.**



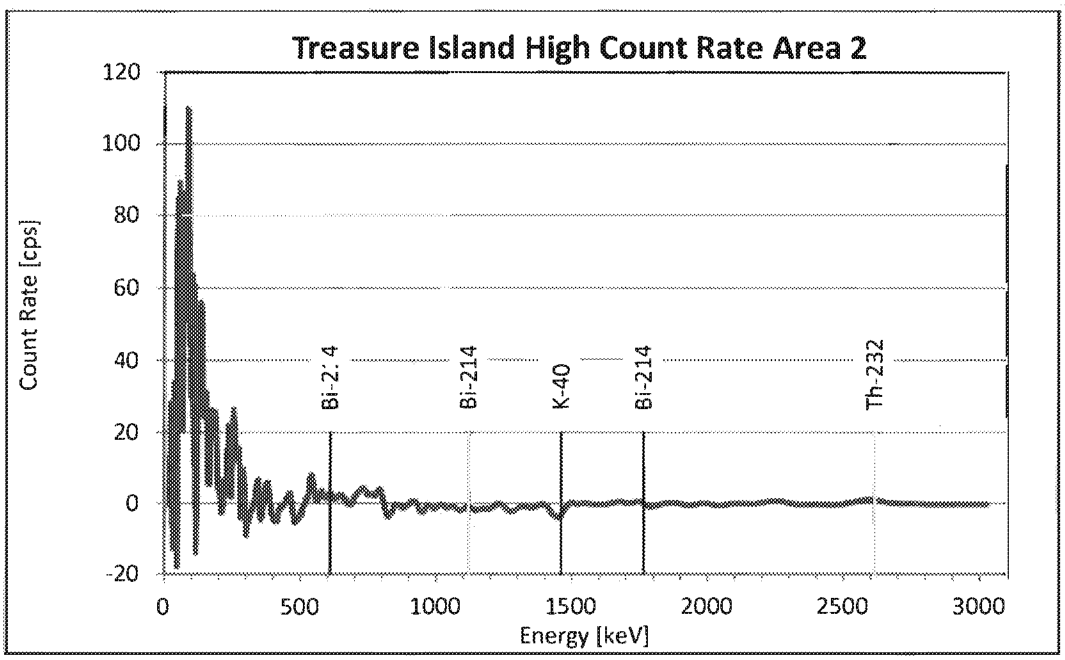
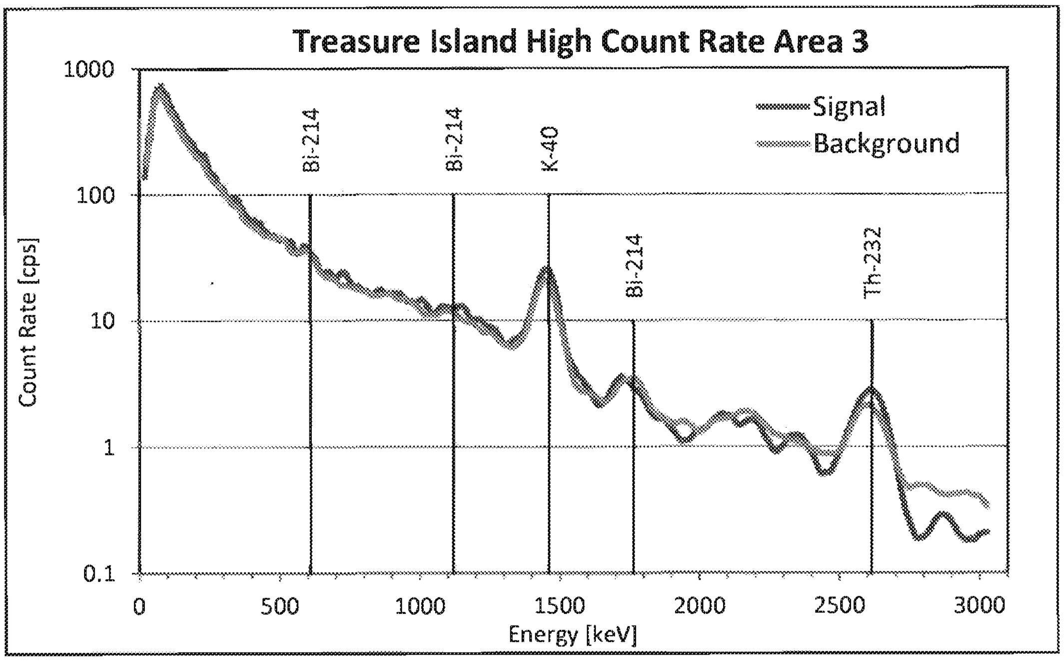




**Figure 21. Spectrum from Treasure Island high count rate area 2.**

**The upper plot shows the spectrum from the area marked by circle 2 in Figure 19 (blue trace) and a background taken from the northern part of the island normalized by total counts above 2500 keV (green trace). The lower plot shows the difference between the signal and background from the upper plot. The result is consistent with no excess radioisotopes. Marked peaks are from naturally-occurring radioisotopes.**



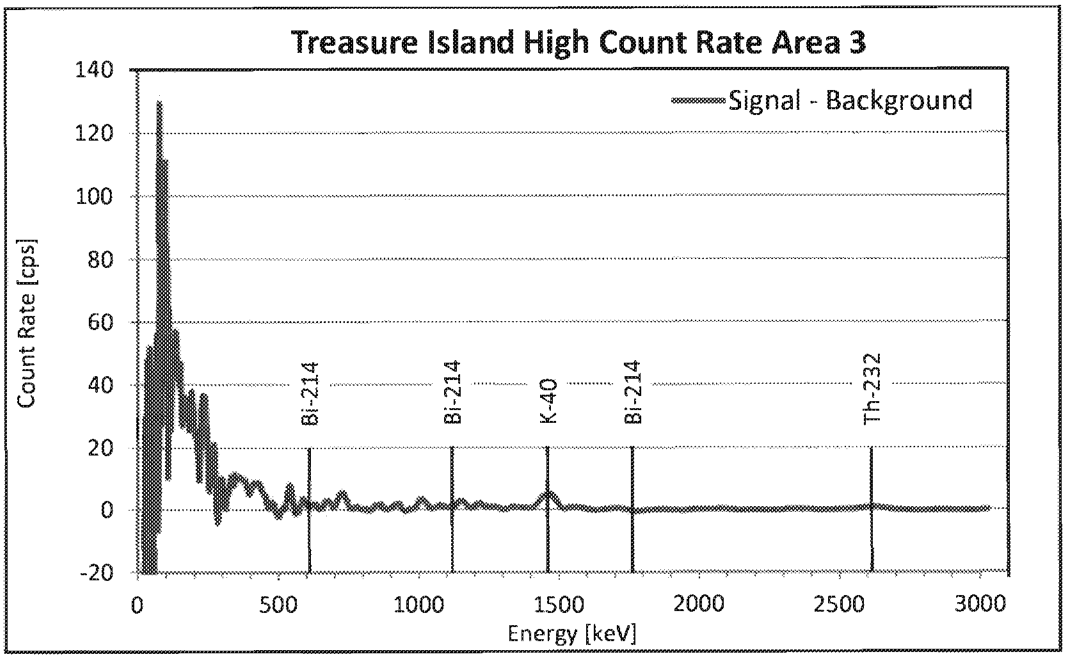




**Figure 22. Spectrum from Treasure Island high count rate area 3.**

**The upper plot shows the spectrum from the area marked by circle 3 in Figure 19 (blue trace) and a background taken from the northern part of the island normalized by total counts above 2500 keV (green trace). The lower plot shows the difference between the signal and background from the upper plot. The result is consistent with no excess radioisotopes. Marked peaks are from naturally-occurring radioisotopes.**

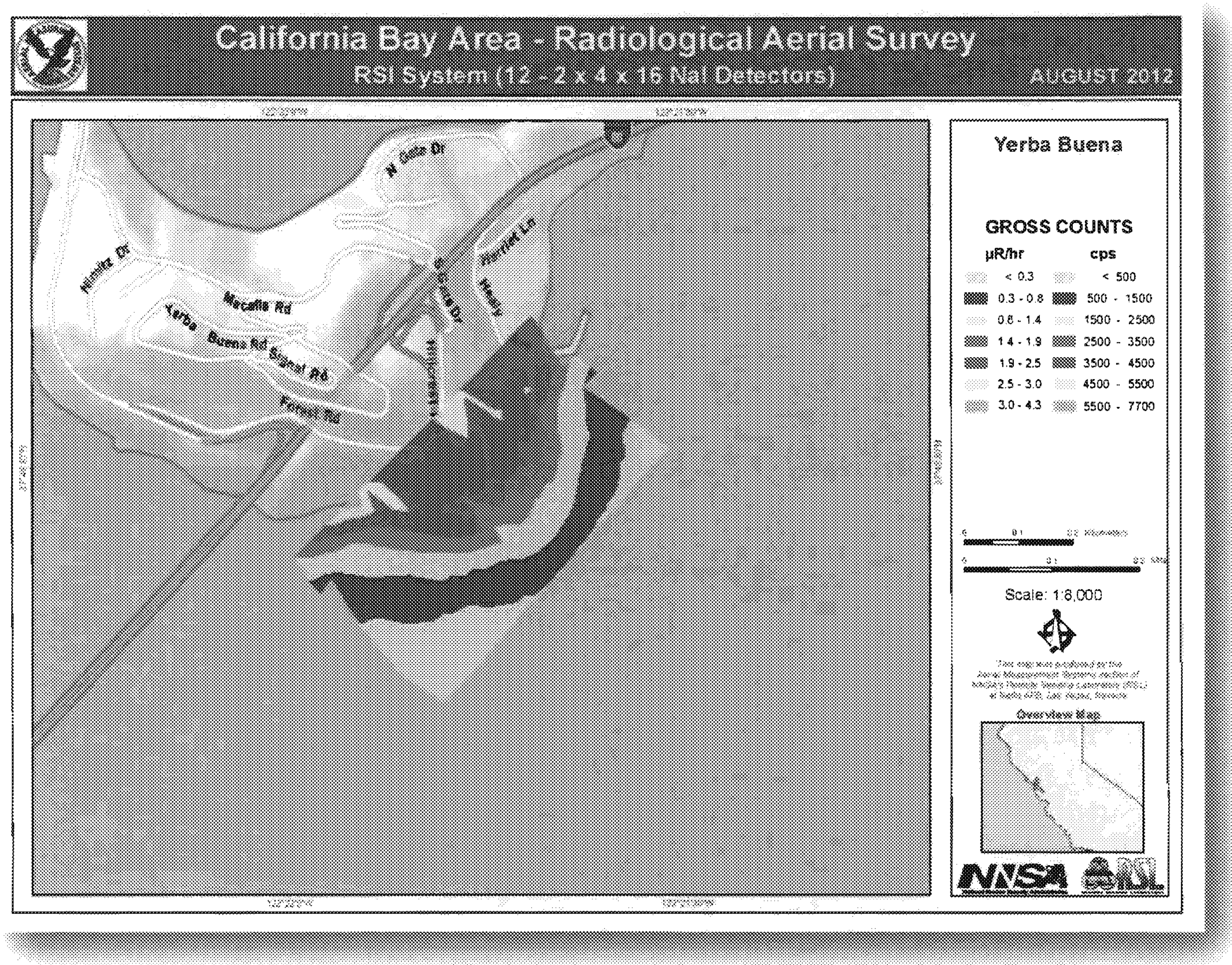



Figure 23. Yerba Buena Island gross count and exposure map.

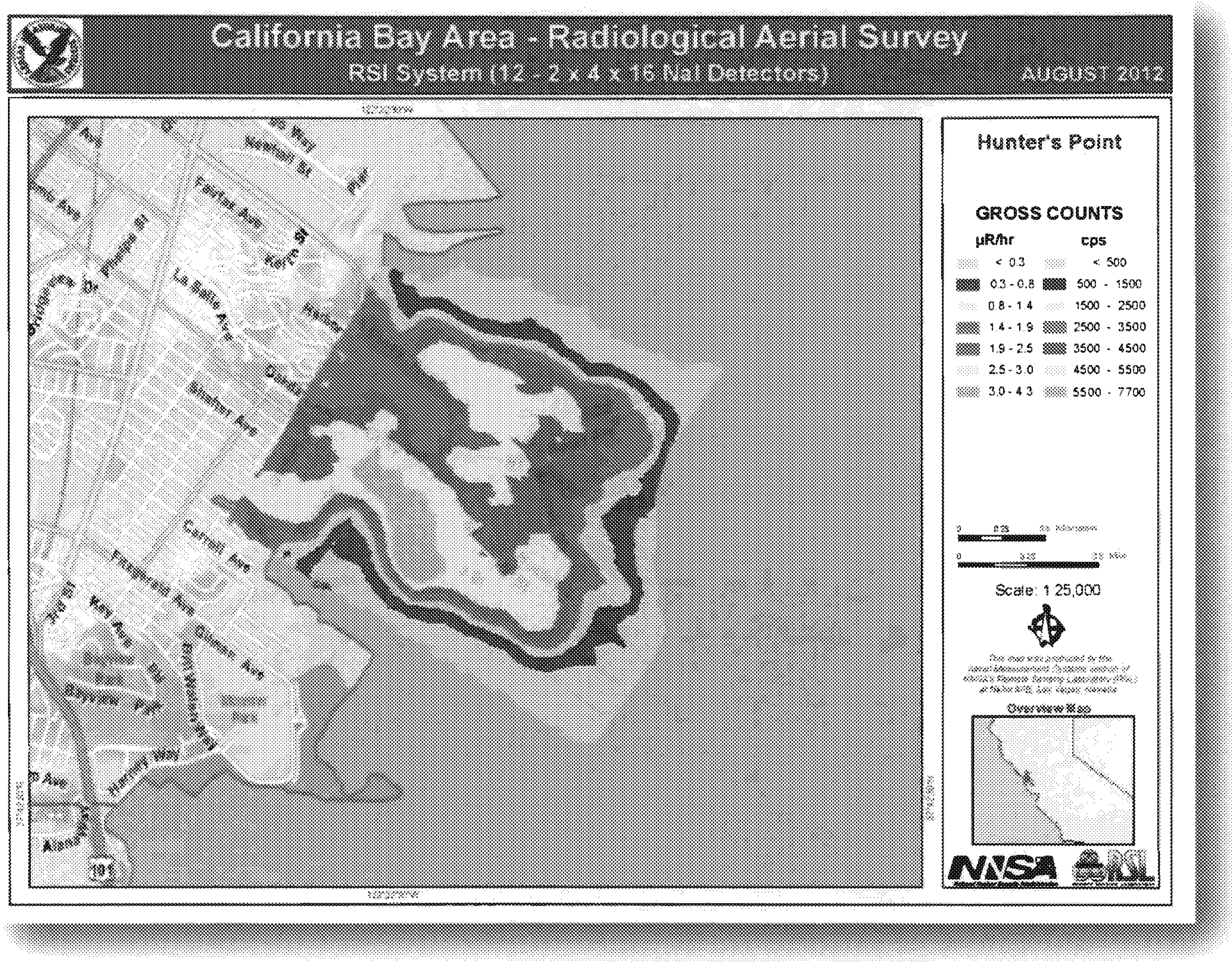



Figure 24. Hunter's Point gross count and exposure map.

The high count rate area is show as orange in the figure.

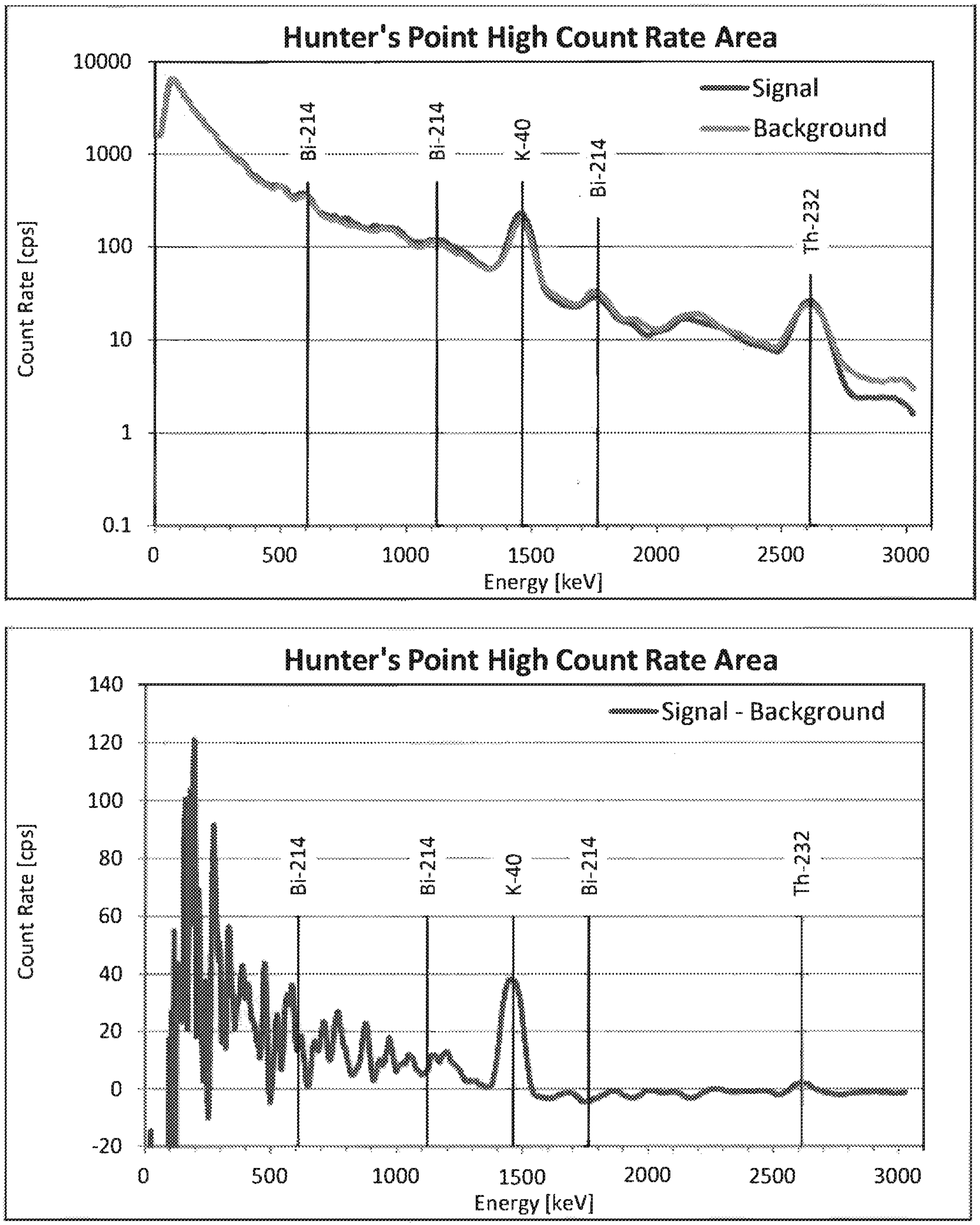



**Figure 25. Spectrum from high count rate area of Hunter's Point.**

**The upper plot shows the spectrum from the high count rate area in Figure 24 (blue) and a background spectrum taken from the northwest portion of the survey area (green). The lower plot shows the difference in these two spectra and reveal an excess of K-40, a naturally-occurring radioisotope, in the high count rate area of Hunter's Point. Marked peaks are from naturally-occurring radioisotopes.**

## References

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Lyons, C., & Colton, D. (2012). Aerial Measuring System in Japan. *Health Physics , 102* (5), 509-515.

Proctor, A. E. (1997). *Aerial Radiological Surveys DOE/NV/11718-127.* Washington DC: U. S. Department of Energy.

# Appendix 1. Survey Parameters

| | |
|---|---|
| Survey Site: | California Bay Area, CA |
| Survey Coverage: | 68 square miles (~176 square kilometers) |
| Survey Date: | August 27 - 31, 2012 |
| Survey Altitude: | 300 feet (~91 meters) |
| Aircraft Speed: | 70 knots (~36 meters per second) |
| Line Spacing: | 300 feet (~91 meters) (Alcatraz 100 feet) |
| Navigation System: | Trimble DGPS (WAAS corrections) |
| Line Direction: | Varied with survey area |
| Detector Configuration: | Twelve 2″ × 4″ × 16″ NaI(Tl) detectors |
| Acquisition System: | RSI RS-501 |
| Conversion Factor: | 1808 cps per μR/h @ 300 feet |
| Air Attenuation Coefficient: | 0.00191 feet$^{-1}$ (0.00627 meters$^{-1}$) |
| Aircraft: | Bell-412 Helicopter |